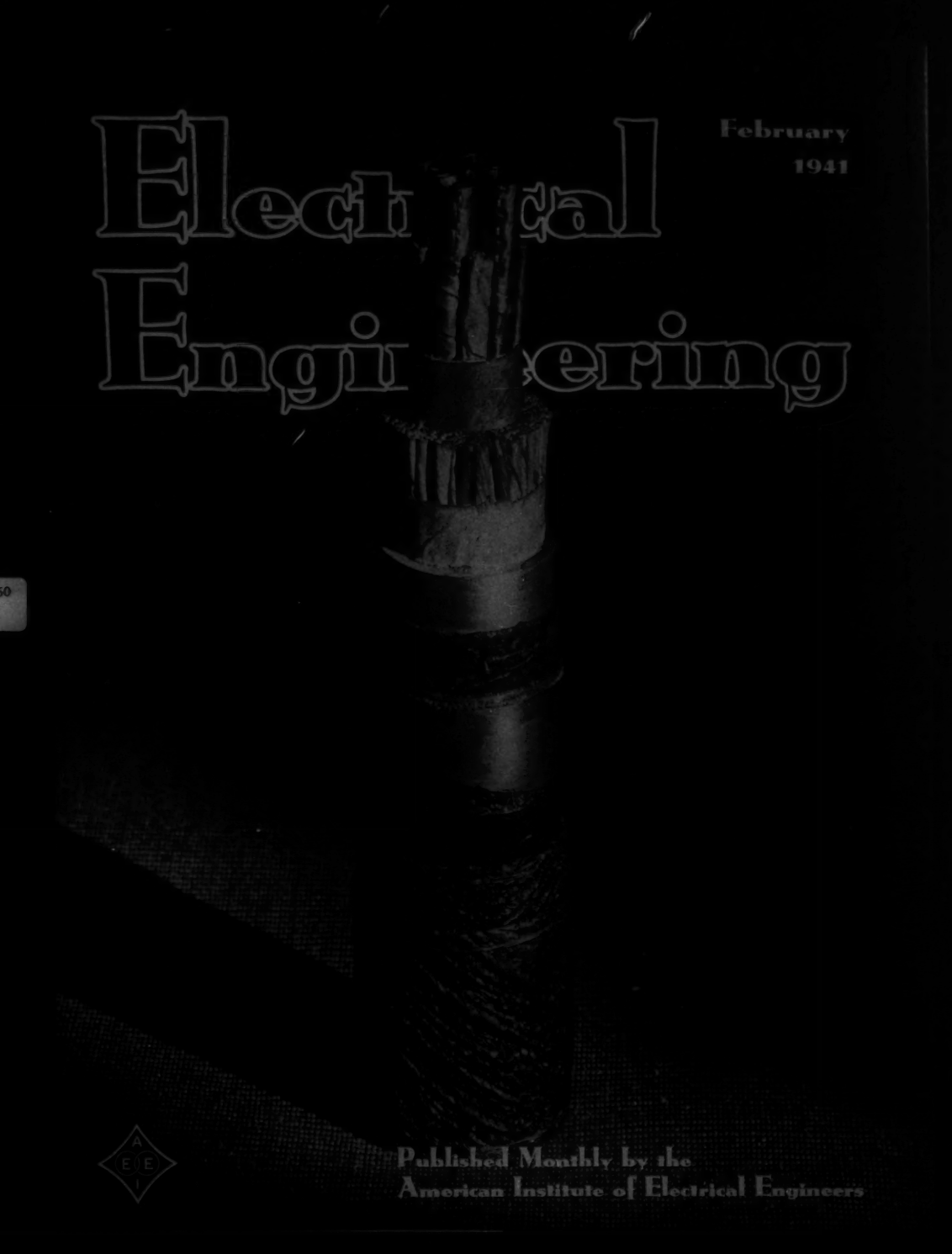
Electrical Engineering

February
1941



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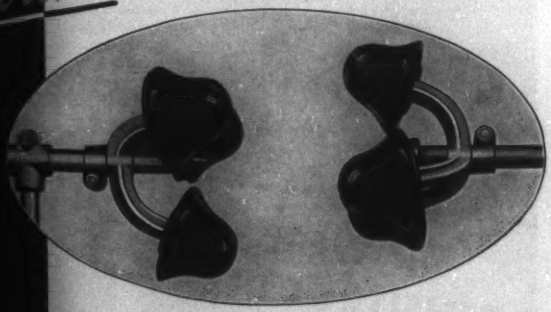

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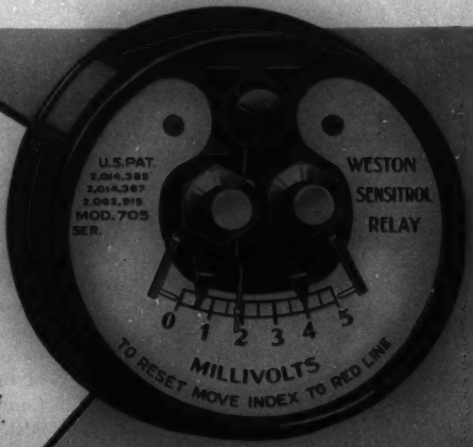

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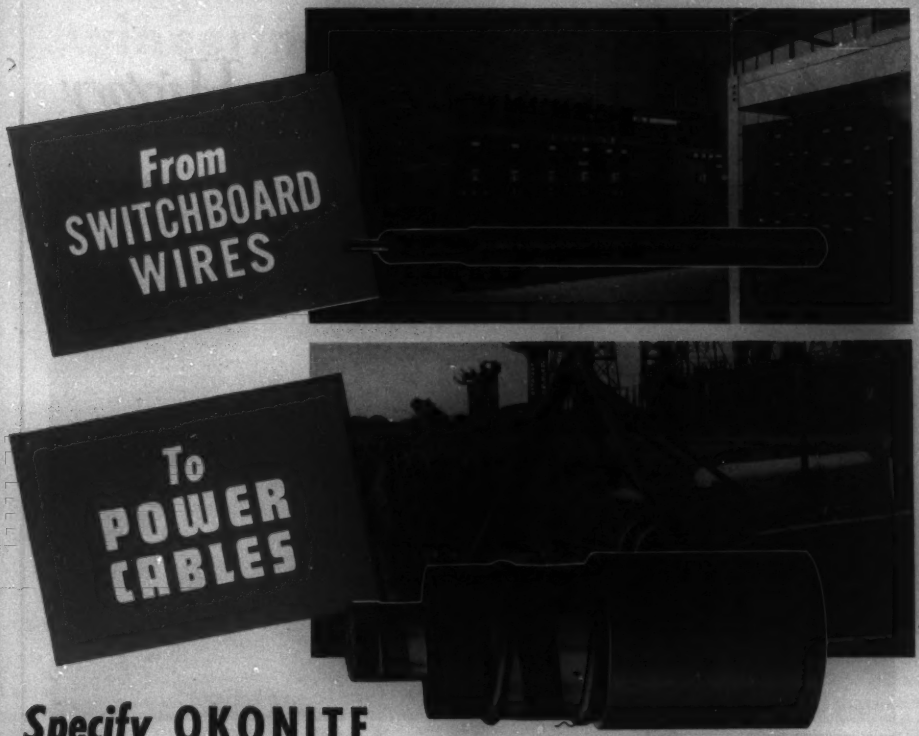

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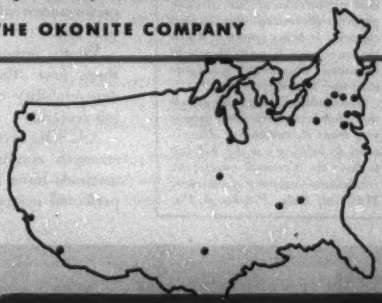

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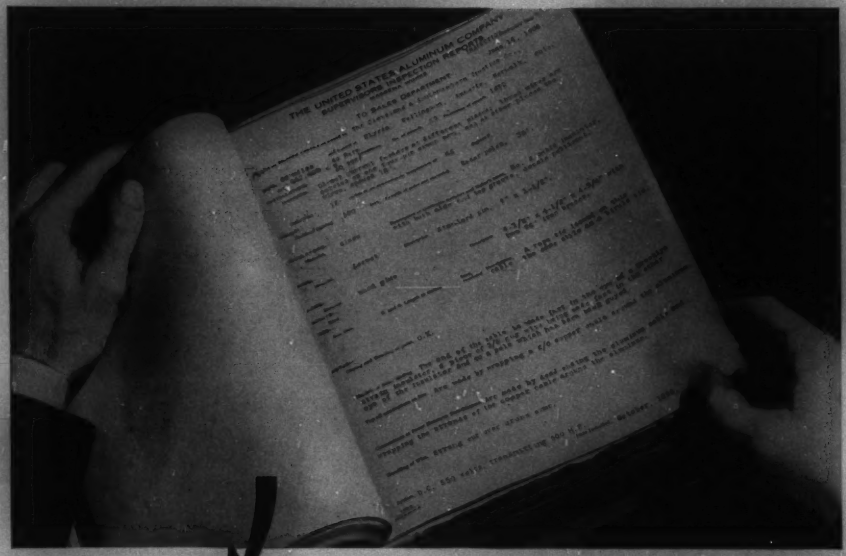

DEFENSE COMES FIRST

To meet the needs of the National Defense Program, plus the normal demands of peace, a vast expansion of our already greatly increased production capacity is being speeded. When the emergency is past, there will be more Aluminum available than ever before.

Meanwhile, if you can't get all the Aluminum you want when you want it, remember Aluminum is helping you by helping to meet the National emergency. Aluminum Company of America, 2149 Gulf Bldg., Pittsburgh, Pa.

From the earliest days of Aluminum power lines, our engineers have been "in the field;" assisting designers and builders, studying the performance of finished lines. Observations were recorded in books like this.

Vitally important to industry was this study of the performance of these first Aluminum lines. Refinements responsible for the great dependability of present-day power lines were based on such on-the-job records.

A.C.S.R. evolved as the use of longer spans required higher strength conductors. Suitable accessories and construction methods have been developed and proved, even including a perfected system of vibration control.

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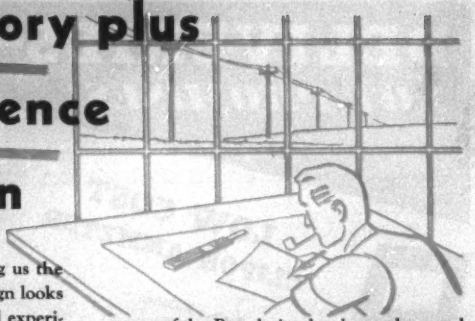
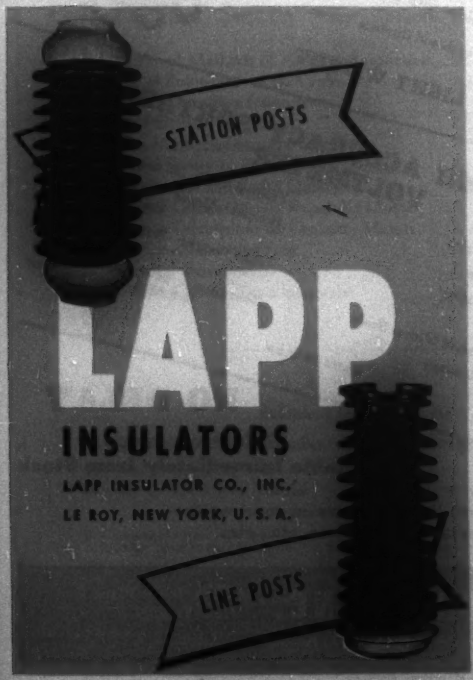
Engineering theory plus practical experience prove this design



For nine years, some engineers have been telling us the same story, "Your Line Post and Station Post design looks like a world-beater on paper. But we've had sad experiences with tricky new stuff. We'll see how it works out before we risk our conductor on it."

Now the Line Post is nine years old. We've put Posts up where no other insulator would stand the gaff. We've had ten-pole "trial sections" stuck in the middle of long lines. We've sold Post insulators for stations and transmission lines from New England to Los Angeles.

And every claim we ever made for the operating performance of the Post design has been eloquently substantiated in the rough-and-tumble of heat and cold, sleet and lightning, dirt and fog. With nothing about them to deteriorate, there's no reason to believe that the Post insulators now in service won't last until the last pole has rotted out from under them.



Every situation under which conventional insulators fail has been encountered by Lapp Post units. And we've yet to hear of the installation in which the Line Posts or Station Posts did not give more satisfactory service than the conventional units which they replaced.

Claims which we have made for our Post design—claims which we are prepared to prove on a sound engineering basis, or from case histories of actual installations—include the following:

Absolute and permanent elimination of insulator-caused radio interference, superior ability to withstand power arcover and mechanical attack from stones and bullets, freedom from puncture and cracking, almost complete elimination of cleaning, and superior performance under fog and dirt conditions, greater rigidity, fewer insulator failures and replacements.

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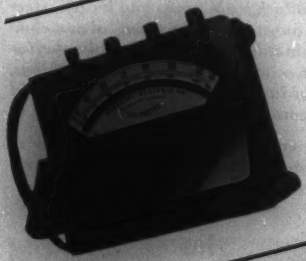

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Electrical Engineering

Registered U. S. Patent Office

for February 1941—

The Cover: Section of Stevens Point–Minneapolis coaxial cable, the first commercial cable of its type to be installed on the Bell System (see page 71)

Photo courtesy "Bell Laboratories Record"

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(Founded 1884)

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¶ Correspondence is invited on all controversial matters.

High Lights • •

Motor-Performance Calculations. A method of calculating the performance of repulsion motors has been developed for the purpose of predetermining the torques and currents, especially for the starting period of repulsion-start induction-run motors (*Transactions pages 67–73*). A calculation sheet presenting the equations of capacitor-motor performance as developed by W. J. Morrill makes it possible to perform all the operations involved in calculating the currents, except the last, without the use of vectors (*Transactions pages 73–6*). The quantities necessary for calculating the performance of single-phase induction motors may be plotted as families of curves, by a time-saving method that eliminates the need of constructing a special diagram for each machine (*Transactions pages 55–8*).

Magnetic Storms. For many years magnetic storms, which occur at irregular intervals, have been known to disrupt all types of electrical communication systems; the storm of March 24, 1940, however, was so severe that it caused not only widely scattered disturbances on communication systems, but also operating difficulties on several electric-power systems in the United States and Canada (*pages 72–5*).

Artificial Respiration. A comprehensive study is being made of the pole-top method of artificial respiration, devised to give prompt aid in cases of electric shock; relative amounts of air moved by this method, the standard Schafer prone pressure method, and the modified Schafer method have been compared (*Transactions pages 41–4*).

Oilless Interrupter. Tests on a high-power circuit breaker using water as the interrupting medium have shown results comparable to an oil circuit breaker. Interrupters using water have already been used fairly extensively in moderate capacities (*Transactions pages 85–8*).

Capacitor-Motor Theory. The cross-field theory, heretofore applied to single-phase induction-motor analysis, has been extended to the capacitor motor; results of this and other analyses on the same motor have been tabulated for comparison (*Transactions pages 58–62*).

Overexciting Transformers. Measurements of harmonic voltages indicate that transformer exciting currents affect system-voltage wave shapes more than is commonly believed; the effects on wave shapes and power factor are discussed in this issue (*Transactions pages 49–53*).

Elevator Buffers. The speed at which an elevator buffer stops an out-of-control elevator at the bottom of its shaft must be limited for the safety of passengers; tests of the striking velocity have been made with a magnetic pickup coil and grooved iron rod (*Transactions pages 53–4*).

Resistance Welding. Improvements in controls and equipment for the various types of resistance welding have kept pace with the growing importance of this method of fabricating metals in modern high-speed industrial production. Recent developments are surveyed in this issue (*pages 75–9*).

Future Air Transportation. Greatly increased use of airplanes for cargo carrying is predicted in an article which urges immediate development of commercial aviation on a large scale because of its importance to the national defense program (*pages 57–63*).

Electric Shock. Results of experiments with a number of subjects provide much-needed information on the magnitude of current which human beings can withstand with reasonable safety; the authors also review the common effects of electric shock (*pages 63–6*).

Unbalanced Wye Circuits. Bringing together the many existing methods of solving three-phase systems with unbalanced wye-connected loads, an article in this issue compares the various methods and presents a numerical example of each type of solution (*pages 80–5*).

Electrical Governor. To control and regulate electrically the speed of hydraulic turbines, a form of frequency meter actuates a pilot valve which in turn controls the operating engine that opens or closes the wicket gates of the turbine (*Transactions pages 80–4*).

Winter Convention. The 1941 AIEE winter convention, in progress at Hotel Bellevue-Stratford, Philadelphia, Pa., January 27–31, as this issue goes to press, gave promise of record attendance (*page 86*). Full report of the convention will appear in the March issue.

Current-Limiting Fuse. To meet the demand for small totally enclosed fuses of high interrupting capacity for transformer protection, a new current-limiting fuse has been devised; tests confirm its reliability (*Transactions pages 77–80*).

Insulator Designs. Standard designs of pin-type switch and bus insulators and of suspension insulators have been analyzed in relation to the suggested requirements of "radio-free" insulators of these types (*Transactions pages 62–6*).

Utilities and War. Some of the problems created for utility companies by war and a war economy are discussed by an officer of a holding company with subsidiaries in the European war area and elsewhere (*pages 67–71*).

Point-Gap Behavior. Results of laboratory work on the behavior of point gaps at 60 cycles have been summarized for the benefit of those concerned with flashover of insulation or insulators (*Transactions pages 44–8*).

Correction. In the article "Trends in High-Intensity Mercury Lamps" by George A. Freeman, which appeared in the November 1940 issue, pages 444–7, the abscissa of figure 1 (page 445) should have read "Time—Minutes" instead of "Time—Seconds".

Coming Soon. Among special articles and technical papers currently in preparation for early publication are: an article on automatic control of aircraft by C. D. Barbulesco (M'40); an article on the technology of motion pictures by Douglas Shearer; an article on airdrome and aircraft lighting; an article on the challenge to industry that will come after the defense program by Charles E. Wilson; an article describing New York City's new Sixth Avenue subway; a paper on calculation of initial voltage breakdowns in air by D. W. Ver Planck (A'31); a paper on the d-c breakdown strength of air and of Freon in a uniform field of high pressure by J. G. Trump (A'31), F. J. Safford (A'35), and R. W. Cloud (A'39); a paper on the audio noise of transformers by W. C. Sealey (M'38); a paper on the automatic printing ammeter by T. G. LeClair (F'40); a paper on the minimum insulation level for lightning protection of medium voltage lines by H. M. Ekvall (A'27); a paper on the impulse and 60-cycle characteristics of driven grounds by P. L. Bellaschi (F'40); a paper on negative damping of electrical machinery by C. Concordia (M'37) and G. K. Carter (A'36); a paper on the analysis of short-circuit oscillograms by W. W. Kuyper (A'34); a paper describing a power-system governor sensitive to frequency and load by Thomas E. Curtis (A'40); a paper on picture transmission by submarine cable by J. W. Milnor (F'30); a paper on hollow-pipe transmission lines of relatively small dimensions by W. L. Barrow (M'33) and H. Schaevitz (A'40); a paper presenting a five-figure table of the Bessel function $I_n(x)$ by H. B. Dwight (F'26); and a paper on the electric strength of air at high pressure by H. H. Skilling (M'34) and W. C. Brenner (Enrolled Student).

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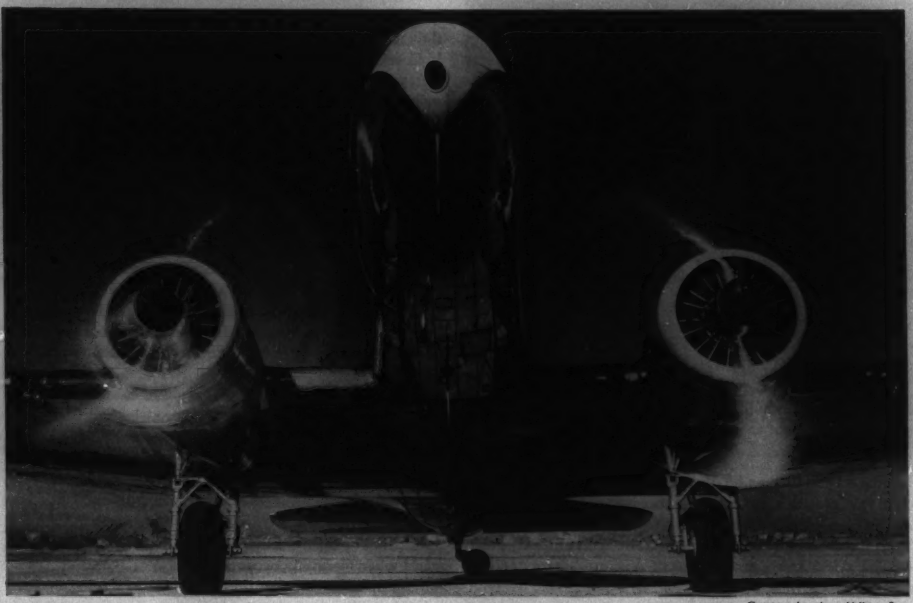
Future Trends in Air Transportation



Courtesy American Airlines, Inc.

GROVER LOENING

Considering commercial aviation in relation to national defense now, and its own potentialities in the future, a pioneer aircraft builder and aviator and well-known aeronautical consultant here outlines a program for the development of cargo transportation by air. Because of the immediate and vital importance of the subject, the conclusions of this expert are particularly significant; comments are invited.

WITH the world at war today and ourselves at least in a very serious emergency phase as a result, the attention of the aviation world, and of those in other fields who are interested in aviation, concentrates so heavily on the military airplane as an offensive war weapon only that we lose an important perspective. The airplane that does not carry any guns or bombs or have any lethal fighting power is also a war weapon, and it is a war weapon of such great importance that we are fully justified in stepping into the war picture with our plea for commercial aviation and its development even in the midst of the roar of guns.

America, in the last ten years, has achieved an outstanding superiority over the rest of the world in the development by private initiative of its commercial air system. American airlines are longer, faster, more used, better equipped, more far-flung, and far more efficient than the airlines of any other country were just prior to the present war. This is due to our competitive system and that alone.

The development of passenger-carrying and privately owned airplanes in this country had become so superior to that of any other country that we found this extraordinary proof: In the United States, throughout its entire commercial air system, both domestic and overseas, not one single airplane engine, propeller, instrument, or in fact any accessory was of foreign manufacture. There are, in fact, practically no foreign-made privately owned airplanes in the air in the United States. And what have we elsewhere? American airplanes, American engines, American propellers, and countless American developments were purchased by and in the use of the airlines of every other major nation in the world. To land on a foreign airport in August 1939 was to see an array of Douglases, Lockheeds, Stinsons, Fairchilds; American engines, American propellers, and American developments

An address delivered at a joint meeting of the New York Electrical Society and the transportation group of the AIEE New York Section, New York, N. Y., January 8, 1941.

GROVER LOENING, B.Sc., A.M., C.E., consulting engineer, is chairman of the board of the Platt-LePage Aircraft Corporation, and also of Roosevelt Field.

Using specially rebuilt planes, the TACA Company transports heavy freight to and from Central American locations

almost as familiar as on one of our own domestic fields. But this priceless advantage is threatened by the supposed exigency of war—threatened by the military mind, acting in its traditional way with perfectly good intent, in all honesty and in all sincerity, but without understanding the value of what might be lost.

It is proposed, therefore, to look at the military lessons to date, to look at the immediate war value of commercial air transport equipment, and to take a peek into the future in order to give a layman and civilian appraisal of why we can claim immediate war-making value to our present commercial aviation setup.

Aviation has always been a strange business—if one can call it a business. Capable men of vast experience who are unfamiliar with aviation are recorded again and again as making in regard to it the gravest errors in judgment.

The industry itself starts out with the greatest of difficulties because from its very inception it is a constant fight of opposing factors. We must build as strong as we can to stand the racking stresses in the air and yet we have no weight with which to incorporate that strength. We must build our planes as speedy as we can to be useful in competition and yet by the same stroke of the drafting pen we must make them as slow as we can in order to be safe in landing. We must produce in tremendous quantities at once with production machinery and yet in the very midst of this we must be able to change instantly in order to meet a new development.

Aircraft production is very different from automobile production. The last war proved it conclusively and this war will repeat the performance. The automobile producer has to learn an entirely new lesson in relation to aircraft, a lesson which the aircraft producer already knows, and that is how to produce in quantity with facility for vital construction changes. The aircraft man knows that a second-rate airplane—no matter how many thousands there are—is of no value.

It is probably these limitations constantly surrounding aircraft development that make it unique, and hence so difficult to understand and judge for those not born and bred in it. Marshal Foch, toward the end of the last war, was told one day by a group of his officers that various aviation difficulties had arisen and had created a crisis. He calmly replied, "A crisis—in aviation there is always a crisis." Our field is better summed up by this statement: In aviation there are no steps in the ladder to success; there are only tightropes.

MILITARY TRANSPORT OF TROOPS

Now let us consider the war. We find the usual lessons, of course—heavier armament, more lethal arms, more performance, more production, more intensive training, and so forth, all in the usual progressive ratio of development that new arms give rise to. In this war we have found one outstanding lesson not heretofore made evident and made only too tragically potent by it. That is the use of aircraft as a transport.

A first instance occurred in the Spanish Civil War when Franco flew his troops from Morocco into Spain. Subsequently, the Hitler Gestapo troops that took control of Vienna, having been stalled on bad Austrian roads, were then carried by commandeered air transport and landed on the Aspen airport. We finally lead up through interesting indications from maneuvers to the lesson taught to the world when Germany occupied Norway. It was air transport more than any one thing that made this occupation possible, military students now agree. The Germans suddenly showed the world that they did not need control of the water between Denmark and Norway when they proceeded to land some 30,000 troops by air at Oslo in a couple of days. Then they went along for months on their campaign, dropping parachute troops here, ammunition there, and guns on the tops of mountains. Finally they even recovered the captured port of Narvik by supplying practically everything needed by air.

So now we have opened a new path for war. Formerly the infantry could laboriously trudge, fight, dig itself in, worm its way through on the ground to its enemy. Then the navy could sweep through the seas and hide itself under the seas and use all the various floating devices to carry itself and its needed munitions to its objective. But now we can vault over the strongest navy in the world and the strongest land army holding a ground position. An air force can laugh at both and blithely jump over to an objective, take, feed it, and ammunition it, with utter contempt for what is on the ground or on the water between.

How does this apply to the United States? It applies more powerfully than to any other nation because we are a nation with distant possessions and distant outposts made so very much nearer by air. Hawaii is only 12 hours from California; Panama is only 6 hours from Florida; Puerto Rico is even less; and Alaska is only 3 to 4 hours from Seattle. What is much more important, New York is only 12 hours from California. But this closely knit

proximity of American points of importance is meaningless unless we have the planes with which to get there and back. That is where our merchant marine of the air assumes commanding importance.

There is a considerable trend on the part of government authorities—and a very natural one—toward feeling that in time of war our commercial airlines should be shut down or taken over. A thorough understanding of what a serious blow this would be to our air strength for war, many of us feel, will surely change this point of view.

Our airlines have developed a highly organized system of maintenance, dispatching, traffic control, etc., that allows for present vast operation of aircraft in commerce. And this operation is very different from Army aviation, as proved by Army experience in trying to fly the air mail in 1934. We have some 400 fast well-equipped modern commercial airliners in service in the United States. As long as these planes are within the confines of the United States or its possessions, they are as much the property of the Army or the Navy as if they were in those services, because they can be commandeered tomorrow morning. And their crews are all trained and ready.

The big lesson to be learned from the war is that they should be commandeered now and then, at least for practice. Last summer some three or four hundred thousand soldiers were moved around the United States in various maneuvers. Not one of these operations was done by air, although private operators had offered their services. In August of 1940 a garrison of 700 troops was sent from New York to Alaska. They were sent on the Army transport St. Mihiel and it took them about 30 days to get there. Right there an opportunity was missed to show what we could do by air. If the government had commandeered 40 or 50 airliners from the various airlines, those troops could have been transported from New York to Alaska in less than 24 hours! Because of the fact that the airliners are in operation, the planes maintained, and the crews on their toes—and they are in the air night and day—they could have been commandeered and found of immediate use at extremely short notice.

Fortunately, the war lesson is being learned. The Army at present is training infantry for air-transport operation. In the present Army Douglas C-39 transport 4,000 pounds can be carried and in tests at Fort Benning, Ga., 37-millimeter antitank guns have been loaded on these planes. As a result of the tests there and at Fort Sam Houston, it has been shown that a war-strength infantry battalion with complete arms and ammunition and other supplies for several days can be transported in 50 airplanes of the ordinary standard type, providing that 4 of these are modified to two-door type to accommodate the infantry battalion guns.

Viewed in the light of war production of planes our fleet of 400 transport planes is not very impressive. There are many suggestions for increasing it. First is the frequently made suggestion that first-class mail be sent by air. According to Captain Edward Rickenbacker, who has extensively considered these possibilities, 10,000 additional air transport planes would be required and 40,000 pilots and co-pilots as compared to the 2,000 pilots that we have

More first-class mail could be sent by air

at present. Such an operation would carry 75 per cent of the annual 350,000,000 pounds of first-class mail.

Three-cent letters average about 32 to the pound; the income, therefore, is 96 cents a pound. A passenger and baggage average about 200 pounds, and at the same rate a passenger could be carried the same distance the mail is carried for $192. However, the average passenger distance traveled in the United States is about 600 miles, and for that distance the fare is about $30 (5 cents a mile). It follows, therefore, that the income from a passenger is considerably less per pound than it would be for 3-cent mail.

If the Post Office Department were to pay 2 of the 3 cents to the airlines, they would make plenty of money and we would have plenty of commercial airplanes available as a reserve for a war emergency.

Another suggestion has been made, which is that we develop the carrying of cargo by air. We will look into this in more detail later.

If, therefore, various suggested means of obtaining a faster growth in air transport were to be expedited immediately, our fleet would grow accordingly until finally we would have so many air transport planes in use in the United States, ready for instant service when called, that we could seriously consider transporting 100,000 troops to Panama, Puerto Rico, Alaska, or Hawaii, whenever we wanted to.

In other words the American Expeditionary Force of the future—and the very near future—is likely to be air-borne, not water-borne. The Leviathan of that era will not be the slow fat ship that the Germans let us take, but more like the new Douglas bomber, the giant new aircraft ordered by the Army, the B-19 that will weigh very nearly

All-American Aviation plane using a new type of equipment to make a pickup at New Martinsville, W. Va.

170,000 pounds gross. It can, with its four engines, carry up to 125 armed troops with complete equipment 3,000 miles nonstop. It can haul 18 tons on short ranges. It can carry 11,000 gallons of gasoline. It is capable of a nonstop maximum range of 7,500 miles and could fly a nonstop round trip to Japan from an Alaska base.

With planes of this type it would be possible to concentrate ten Army divisions in Florida and with a fleet of 1,000 such giant aircraft transfer them to points on the Brazilian coast 3,000 miles away in about 15 hours. Well over 100,000 troops spirited from this country for the protection of a neighbor overnight—this is what the future of troop and ammunitions transport will permit when we finally organize a real air force for this country.

TRANSPORT OF CARGO

Now let us take the next important consideration—the transportation of bulk cargo by air. At first glance most people dismiss aircraft as a serious load carrier. But we know now what we may safely predict to an incredulous world, that will learn only after a lapse of a few years that we were right. Bricks, cement, steel beams, and all other manner of goods will be carted around the skyways of the United States by air at 300 miles per hour in the coming decade, because it will be so cheap, despite the speed!

The facts of 1940 indicate this and the least we can do is to look at them. A modern trailer truck carrying an average of 10- to 12-ton loads, using a 100-odd horsepower engine and a two-man crew, will travel on our magnificent roads at an average of 25 to 35 miles per hour day and night, including necessary stops. The costs of trucking vary considerably, but a general average shows that cargo movement in these vehicles will cost somewhere around 3 cents a ton-mile and the average charge for this service runs up to 4 cents a ton-mile, the rate varying, of course, on different articles. These large tractor trucks cover about five miles to the gallon of gasoline and the cost of operation, including depreciation, is roughly 21 cents a mile.

The truck companies that operate between Florida and New York and other parts of the north generally carry north agricultural products, citrus fruits, etc. On the return trips they carry anything from a bird cage to a cannon. They carry furniture, ladies' dresses, and all kinds of merchandise.

Because of the number of itinerant truckers (the privately owned subterfuge to avoid regulations) the total amount of truck traffic between Florida and the north is difficult to estimate, but it runs to several million pounds a day. With the advent of real cargo-carrying planes—of which there are several in the United States fully tested and in production, some of us rather timidly a short while ago began to compare their cost with that of trucking. We were rather startled.

Among the best developed of these planes today is the Douglas C-39 cargo transport which is used by the Army. One of the older types which was very successful was the Curtiss Condor, now very widely used in South America. Cargo versions of the Lockheed and Douglas and other airliners are in wide use all over the world. The latest entry into this field, now in production, is the Curtiss-Wright C-20. This plane weighs 45,000 pounds. It is powered by two Wright 1,500 horsepower engines. It can carry a load of well over 16,000 pounds (8 tons). This load can be carried a nonstop distance of 800 miles at a cruising speed of 215 miles per hour.

What is still more important is that the C-20 has a cargo-capacity volume of 2,760 cubic feet. That is just about the volume of a freight car, which is a little under 3,000 cubic feet. The freight car can carry between 20 and 30 tons, while the cargo plane carries 8 tons.

Once and for all then, we have settled the dispute over the question of space. In cargo-carrying planes there is more space per ton for the cargo to be carried than in freight cars or trucks.

The greatest development of cargo carrying by air has been achieved in Central America by the TACA Company, now a division of American Export Airlines. This company does a gross business of more than 30,000,000 pounds a year, carrying everything from merchandise, food, and machinery to bulk ores, chicle, and even livestock. Regions otherwise wholly inaccessible are provisioned by air freight exclusively.

An example is illuminating. Let us say we wish to carry 800 tons of cargo from New York to Miami in two weeks' time. By more or less continuous going, night and day, trailer trucks can make a round trip between Miami and New York within a week, so that we would have two round trips per truck required, and since we have to carry 400 tons on each trip, and each truck carries 10 or so tons, we would need about 40 trucks. An airplane at 200 miles an hour, including one brief stop for fuel, will cover the distance from New York to Miami in six hours, and with a suitable number of hours for turn-around and maintenance could make ten round trips a week. One airplane of the C-20 type carrying 8 tons each trip in two weeks' time will transport 160 of our 800 tons of cargo. So to carry the

800 tons in two weeks' time we would need only 5 cargo-carrying planes instead of 40 trucks.

The purpose of this example, of course, is to show that the airplane, light and small as it is, is a load carrier by virtue of its speed and consequent ability to build up ton-miles quickly. Where the bulk of the freight car and the truck are impressive as load carriers, the "to-ing and fro-ing" done by the airplane must be envisioned to appreciate its load-carrying possibilities.

When we take into account the cost of gas per ton-mile, operating costs, taxes, depreciation, etc., we find for a cargo plane of this type a direct cost of 5.3 cents a ton-mile and a charge of about 8 cents a ton-mile with overhead and profit proportional to those of the trucking system.

All the items in a typical load of a trailer truck can be carried in cargo aircraft existing today, at a cost only slightly more than twice the cost of heavy trailer trucking. Then, too, they can be carried at a speed almost ten times as great as that of trucking, which brings in other economies to balance the cost.

From this we can estimate that if air cargo planes are carried up in size—which they most certainly will be—to a gross weight of 200,000 pounds and the ability to carry a pay load of 40 tons, their cost of operation will be down to under 4 cents a ton-mile. That is why some of us are able to predict to you where we are heading in this business. The 300 mile-per-hour airplane of the future literally is going to take business away from the dray horse, because it is cheaper despite the fact that it is so much faster.

PRESENT-DAY LIMITATIONS

Of course there are limitations to this air cargo development. First is the fact that due to the war exigencies, the authorities in Washington do not feel that equipment can be released for cargo-carrying development because it is needed for war. That is why it is so important to impress upon everyone that the development of a vast air cargo system in this country is absolutely a preparation for war and in fact one of the most needed of all. There is no use having long-range operations of bombers and air bases if we cannot supply them.

The next limitation is of course airports. The airplane must have its field. The airports generally are removed from the factories and big centers of industry and inconvenient transshipments that are costly and time-consuming are necessary. But do not dismiss this too quickly as a fundamental handicap, because the aviation industry is going to surprise you.

To begin with, the general tempo of business is such that executives, government officials, engineers, etc., fly to and from their business appointments and will continue to require enormous amounts of passenger air transport. Passenger air transport is already 17 per cent of Pullman traffic and will increase as additional airports become available. Not only are many more airports being built by the government but many large private companies are contemplating having their own fields at their factories. But we recognize that this is not enough, so what we have up our sleeve is beginning to be evident.

The first development we have in actual service—successfully demonstrated and now already in wide use—is the air pickup system. This makes the roof of every large factory a potential station for the transfer of air cargo. An airplane lets down a hook that snares a line to which is attached a package, weighing up to 100 pounds, and draws it up into the airplane, without landing. Deliveries are made in a similar manner by dropping the cargo in special containers by parachute. While air pickup today, in two years, has progressed only to small loads—largely mail and a little express—there is nothing technically to prevent its further development into much heavier units. Even today one aviation company, All-American Aviation, Inc., is operating in ten states with 108 stations.

Next come the aeronautical engineers tackling the most difficult technical construction problem that the industry has faced in its entire history—the development of the helicopter. This is the type of aircraft that lifts and lands vertically, doing away with the landing-field limitations of air transports, and making every large level roof or tennis-court-size strip of lawn a perfectly good landing field. We are at the threshold of this development—at the threshold of having in the air helicopters that will lift a ton. In the dim future they may gradually catch up with the load-carrying plane of many tons.

Third, our engineers are covering a lot of new paper with designs for the final development we need, which is to carry on the cargo liner a small delivery-truck tender in the form of a slow-landing plane or helicopter that will take off from the back of the big plane, land or pick up its cargo, and return into the air from any location where cargo is available. The latter, of course, is in the distant future, but is the directly indicated development of the "pick-a-back" plane that has been demonstrated so successfully on trans-Atlantic flying and may still have a very broad influence on war design. In particular, its design is likely to be expedited by the necessity of long-range bombers carrying their little fighter planes within them and launching them when they get to an objective thousands of miles away. This suggests clearly the prospect of large cargo-carrying transcontinental planes making pickups and deliveries at mall intermediate stations by the use of auxiliary planes.

These various future considerations lead us to a very important conclusion, which is: Limitations of aircraft resulting from their inability to make local pickups and deliveries are going to disappear, so that we end with an air vehicle for transporting cargo from anywhere to anywhere else, and doing so at speeds that cannot be even

A Focke-Achgelis helicopter taking off

Army YG-1 autogiro, Kellett Autogiro Corporation

approached by terrestrial or water means of transportation.

THE REALITIES

Let us leave this fascinating future for the moment to look at the realities. Why have we so little cargo carrying in the air in the United States?

The reason is simple. Believe it or not, air cargo carrying in the United States is a monopoly owned by the railroads—a fact generally not known. The 70 major railroad systems of the country own the Railway Express Agency. This company has with each airline exclusive contracts containing the following items: First, no express or freight forwarding or delivery company except the Railway Express Agency can handle air cargo for the airline—suggestive of a clear monopoly. Second—no rates can be made less than twice that charged on the railroads—a clear suggestion of price-fixing. Actually the air rates are held at five to seven times railroad rates.

The Railway Express Agency does a gross business of some $170,000,000 a year. Of this the Air Express business is a little over $2,500,000 a year—about 1.5 per cent. At the time these contracts were made, they were no doubt justified. But our whole system of carrying cargo in the air started out wrong and has never been able to achieve any serious proportions. Obviously, of course, the high rates are the principal reason. Actual Air Express rates at present average 80 cents a ton-mile, which is from 5 to 7 times higher than Railway Express rates.

We mentioned earlier that cargo planes could be run at about 8 to 10 cents a ton-mile. Actually, Railway Express rates—not Air Express rates but ordinary railway rates—run from 10 to 15 cents a ton-mile. So today we have proof that aircraft can carry express for less than the rate for express carried on the railroads, if done in enough volume.

In the month of October 1940 the passenger carrying on the domestic airlines totaled up to the amazing amount of 116,000,000 passenger-miles. Since the passenger and his luggage average 200 pounds, the number of passenger-pound-miles carried by the airlines totaled 23,200,000,000 pound-miles. During this same month the air mail that was moved amounted to 1,894,000,000 pound-miles. But the express cargo carrying on all the airlines that month amounted to only 731,000,000 pound-miles, or less than 3 per cent of the gross for the airlines for that particular month. The revenue from passengers for that month was $5,800,000 and the revenue from mail was $1,700,000. The revenue from express was $365,000. As a typical example, we can take United Air Lines, which earned a gross during that month of $1,692,000. Of that gross, the gross income from the carriage of express cargo was only $91,000.

The express companies and the airlines announced that this year Air Express business has increased 30 per cent. That sounds big, but it really means an increase from 3 per cent to 3.9 per cent of the total traffic. With potentialities, the business should increase from 3 per cent to 80 per cent—a volume more proportionate to what cargo earnings are in other transportation systems.

The only justification that can be found for the railway setup is that the Railway Express Agency furnishes a pickup and delivery service. But, as has been indicated, air developments taking place right now will eliminate the necessity for much of this. The railways and the trucking companies can no more stop the steady and inevitable advent of air carriage into the transportation field than they can stop the sun from rising by hanging on to the hands of the clock.

SPEEDING UP DEFENSE

We have still to consider the most potent immediate reason for a vast extension of air-cargo carrying. That is its use in speeding up construction of aircraft and munitions for defense.

Most major aircraft factories have their own flying fields right at their doors. Further, in the present rush to produce aircraft in great quantities a great deal of subcontracting is being done by these large aircraft plants. I quote a recent press release showing government recognition of the importance of this "farming out".

"Explaining the farming-out principle, the War Department declared that that principle is rapidly becoming important in this country as a means of breaking up defense contracts so as to bring into use reserves of idle equipment. As the defense program continues to put an ever-increasing burden on large manufacturing facilities, the expedient of using small units of production will be resorted to more and more...."

The Undersecretary of War, Judge Robert B. Patterson, has pointed out how very important the small machine-shop operator is in the defense scheme and that the "farming-out" of orders would have the effect of preventing too great migration of workers and of forestalling housing shortages. But the prime contractor must still take full responsibility in selecting his own subcontractors. With a cargo air service operating between the various main contractors all over the country and with a pickup service capable of handling small units, the scope of the prime contractor is immensely increased, with a consequent general speeding-up of his entire production. For example, the Glenn Martin Company, at Baltimore, Md., has a 3,500 ton press, useful for large operations in airplane manufacture, and a machine tool hard to duplicate in present defense congestion. With sufficiently fast cross-transportation between aircraft factories, this press could

be used to press out material for other manufacturers who do not have such a machine. And for trouble-shooting, the wide use throughout the country in this munition emergency of the quick shipment of needed parts by air would save literally millions of man-hours of labor before the end of the year.

Little do we realize the magnitude the air industry itself is attaining until we look over the results to date. The Bureau of Labor Statistics indicates that the 203,000 workers in aircraft factories in October 1940 will have to be increased to 455,000 by October 1941. When accessory establishments in addition are included, the grand total of employment in sight for the fall of 1941 in the aircraft business is 555,000 workers! This means that within the year the aircraft industry will become almost the largest employer of factory labor in the country, while two years ago it was almost an insignificant industry so far as employment was concerned. In September 1939 the nation's leading aircraft factories had a total of 9,000,000 square feet of working floor space. By November 1940 this working area had been increased to 17,000,000 square feet. By 1942, when the present expansion programs are completed, the industry will have grown to 33,000,000 square feet.

To this industry the addition of a comprehensive air cargo transport system would be the simplest kind of development, because the airfields are already at its doors and all those connected with it are completely air-minded, and as a result munitions-making would be enormously speeded up.

At the end of this emergency, the enormous production facilities that will have been developed will need a market, and no market will be more tempting than that of cargo carrying by air.

We may forecast here, therefore, a tremendous era of rivalry and intensive competition and a lowering of rates. Load-carrying planes, bombers, etc., delivered into a second-hand market status, will be used for the carriage of all manner of goods, and flown by all manner of ex-war pilots, to a degree that might lead to as much confusion as there is now in the trucking business if we do not undertake at once to organize it along much more manageable lines.

The immediate development of cargo carrying by air in great quantities is thus seen to be a defense measure, and in fact one of the greatest contributions that the air industry can make to the nation's defense. Not only would it provide a fleet of planes available at a moment's call to defend the country by carrying troops and munitions to our possessions and outposts, but by speeding up transportation would hasten production of munitions. Carriage of air cargo, therefore, must be regarded as one of the most important of the new developments crying for immediate attention today.

Effects of Electric Current on Man

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With increasing use of electric fences, insect screens, and other devices having exposed electrodes, information on the magnitude of electric current that is safe for human beings becomes of great importance in determining regulations and safety codes. The authors report the results of experiments showing the maximum 60-cycle alternating current and direct current which the average man can withstand with reasonable safety.

THE danger of exposure to electric shock has been increased by the widespread use of devices having exposed electrodes, such as the electric fence, the electric insect trap, the electric fly screen, and the electric cattle prod. Many of these devices are purchased and installed by persons who are not familiar with the principles involved or the dangers inherent in such apparatus. Because of the simplicity of construction, convenience, and economy afforded by the electric fence, many types are offered by small manufacturers or constructed by novices with little or no regard for safety. Some of the homemade varieties are energized directly from lighting circuits protected only by ordinary fuses. In others the current is limited to about 62.5 milliamperes with a $7\frac{1}{2}$ watt incandescent light. More elaborate devices have been constructed using radio parts and thermostatic interrupters. The authors recently tested one of these devices and found that the interrupter failed in the energized position when a resistor equivalent to the human body resistance was connected to the fence terminals. Many of these devices have proved unreliable or ineffective, and have caused numerous animal fatalities. Quite recently regulations governing some of these devices have been adopted,[1,2,3] but the issue is far from being closed.[4]

Several human deaths have been caused by contact with electric fences,[5,6] and in the light of existing conditions it

Based upon a paper "Electric Shock" by the authors and J. L. Thurston, presented at the AIEE winter convention, January 27–31, 1941, Philadelphia, Pa. Research was aided by a grant from the California Committee on the Relationship of Electricity to Agriculture. The authors wish to express their gratitude to the many men who volunteered for the experiments, which could not have been conducted without their co-operation and continued interest. The authors are indebted to J. L. Thurston, C. J. Manner, J. R. Burch, and S. H. Robley, students in electrical engineering, for their assistance in obtaining and analyzing the data.

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1. For all numbered references, see list at end of paper.

Figure 1. One of the test subjects at his 60-cycle let-go current

is indeed surprising that the number of fatalities has been so small. While some regulations have been adopted, the preparation of adequate regulations and the formation of safety codes have been impeded by lack of scientific information as to the amount of current that is safe for man. In the interest of public safety, it is essential that legislation be provided to permit only the sale and use of *approved* devices.* The public must be protected against the purchase of dangerous products.

An investigation of the energy requirements and safety of electric insect traps, undertaken by one of the authors in 1936, showed that no reliable information was available on currents required to control animals or to kill insects. Of much greater importance, there was little information available on the magnitude of electric currents safe for man. Therefore the original scope of the problem was expanded to include a study of the general effects of electric shock on man. This paper presents results obtained on direct current and 60-cycle alternating current. (For details of the experimental procedure, data, curves, and statistical analysis, see reference 12.)

A brief review of the effects of power-frequency currents on man may prove interesting and instructive. The threshold of perception is about one milliampere when electrodes are held in the hands. A very faint tingling sensation is first felt. This rapidly increases in intensity as the current is increased, and at the same time involuntary muscular contractions of the hand and wrist appear. These increase in intensity and progress up the arm to the chest with currents of 10 to 15 milliamperes. From 15 to 20 milliamperes the muscle contractions are severe and painful, and a sensation of mental discomfort difficult to describe may appear. At 20 milliamperes or higher, the chest muscles become involved, and breathing becomes somewhat difficult. Up to a certain point an individual can still release the electrified wire in spite of the involuntary muscular contractions. The authors have called the highest current at which muscular control is still possible the "let-go current".

The main object of our investigation was to determine the let-go currents of a large number of subjects. Of the 114 men tested on 60-cycle alternating current, the average let-go current was 15.5 milliamperes, and the highest was 21.6 milliamperes. In order to get an accurate determination, it was necessary to go above the let-go current of each individual. However, none of the subjects was given more than 2 or 3 milliamperes in excess of his value. What happens at values slightly above this is conjecture, at least as far as the authors are concerned. The subjects were exposed to the current for a matter of seconds only, just sufficient to give them time to exert a determined muscular effort. This exposure is distinctly in contrast with that of individuals who grasp an electrified wire and have to endure it until aid reaches them. The effects of fear must play an important role in these instances. The tetanic contraction of the chest muscles might be sufficient to interfere greatly with breathing, and after sufficient exhaustion from muscular effort, death might occur from asphyxiation. Currents in excess of those that cause involuntary cessation of breathing, due to effects on the muscles, are believed to result in temporary paralysis of the nerve centers which may paralyze the respiration for a considerable period of time even after interruption of the current.[7,8] Somewhat higher currents cause ventricular fibrillation, which results in death due to failure of the heart muscle. The minimum current necessary to produce ventricular fibrillation in man has been estimated to be about 100 milliamperes for shock durations of three seconds or longer.[8] Once the human heart muscles begin to fibrillate, little can be done to save the victim. Currents considerably in excess of this value cause violent contractions of the body musculature, and are believed to suspend the action of the heart, instead of causing it to fibrillate.[9] The heart may resume its normal rhythm upon interruption of the current, or it may do so if resuscitation measures are applied promptly. Relatively large currents (amperes, *not* milliamperes) produce sufficient heat to destroy nerves, muscle, and bone and to cause hemorrhages. Major damage to vital organs, especially that resulting from electric arcing, may be so severe that death is inevitable. Delayed death may be due to burns, hemorrhages, or other complications.

In many high-voltage accidents the combination of high contact resistances and severe muscular reactions results in limited currents of short duration. These may cause respiratory paralysis and cessation of breathing. The heart may continue to beat, it may fibrillate, or, which is more likely, it may come to a standstill. Thereupon

*"Approved" means approved, labeled, or listed as conforming to the standards of the National Bureau of Standards, the Underwriters' Laboratories, Inc., the United States Bureau of Mines, or other similar institutions of recognized standing.

unconsciousness and apparent death occur. However in many instances the victim may be saved. Since a layman cannot distinguish between these various possibilities, he should immediately give the victim artificial resuscitation. This should be continued until death is diagnosed by a physician, until *rigor mortis* sets in, until the body becomes cold, or until the victim revives. The value of the Schafer prone-pressure method or the newer pole-top method of resuscitation[10,11] must be emphasized, especially to men in the field. Nevertheless, the best means of reducing the present fatality rate of about one in 100,000 is instruction in the proper procedures for electrical workers, education of the public in the use of electrical equipment, and rigid adherence to safety codes. It is encouraging to note that only a very small percentage of the victims who recover from an electrical injury show any permanent disability.

THRESHOLD OF PERCEPTION

The threshold of perception was determined for direct current and commercial 60-cycle alternating current. Each subject sat in a relaxed position in a chair with the palms of the hands resting on two number 7 copper-wire electrodes. The hands were moistened with a salt (sodium chloride) water solution in order to reduce contact resistance and permit the use of low voltages for safety. The current was gradually increased so that the subjects might become acquainted with the faint sensations of warmth and tingling. Repeated tests were then made to determine the smallest current that could be felt. The average of several trials was taken as the threshold value. The 60-cycle threshold current for 115 men was: 1.1 milliampere average, 0.4 milliampere minimum, 4.0 milliamperes maximum. The results are in close agreement with the generally accepted value of one milliampere.[8] The threshold of perception for direct current for these 115 men was: 5.2 milliamperes average, 2.2 milliamperes minimum, 12.6 milliamperes maximum.

The tongue is probably the most sensitive organ likely to experience direct contact with a source of potential. In fact, a popular method of testing dry cells is to touch the battery terminals to the tip of the tongue. It was therefore considered of interest to determine the minimum current that is perceptible. Each subject sat relaxed in a chair and held two platinum test electrodes lightly on the tip of his tongue. The electrodes consisted of two number 18 wires one inch long and spaced one-half inch apart by means of a Bakelite separator. Platinum wires were used to minimize galvanic effects. The threshold value varied over a wide range among the subjects tested, and there was considerable variation in repeated tests on the same subject. As before, the threshold was taken as the average of several trials. The 60-cycle threshold for 115 men was: 43 microamperes average, 4.0 microamperes minimum, 315 microamperes maximum. The threshold for direct current for the 115 men was: 44 microamperes average, 0.6 microamperes minimum, 783 microamperes maximum.

Figure 2. The subject shown in figure 1 at about two milliamperes in excess of his 60-cycle let-go current

LET-GO CURRENTS

In these tests the subject grasped a test electrode consisting of a 12-inch length of number 6 copper wire. The circuit was completed by placing the other hand on a flat brass plate 8 inches in diameter. This permitted the subject to break the circuit at any time he desired, even though it was necessary for an observer to hold the hand flat to prevent it from curling (see figures 1 and 2). The current was gradually increased to accustom the subject to the sensations produced. After one or two trials, the current was increased at a moderate speed to a certain value, and at this point the subject was commanded to drop the test electrode. If he succeeded, the current was increased by steps until he was no longer able to let go of the wire; if he failed, the test was repeated at a lower value. The end-point was checked by several trials, insufficient in number to cause fatigue, but sufficient to permit an accuracy within a range of about 0.5 milliampere.

Preliminary tests indicated that it was immaterial whether the other hand or one of the feet was placed on the indifferent electrode. They also indicated that the let-go current was unaffected by the surface condition of the hands, tests having been made with dry hands and hands moist from perspiration, salt, and weak acid water solutions. The standard procedure was to keep the subject's hand moistened with a weak salt solution during the tests. This was done in order to secure more uniform conditions, to lower contact resistances, and particularly to lessen unpleasant sensations at localized tender spots due to high current densities. As the salt solution dried on the hands, the voltage and resistance increased, although the let-go current remained substantially the same. It had previously been found by tests with open-circuit voltages from 5 to 9,720 volts that sensations and muscular reactions were proportional to the current and not the voltage. These two findings confirm the generally accepted opinion that current and not voltage is the proper criterion of shock intensity.[8]

Figures 1 and 2 show pictures of subjects near the limit of muscular control on 60 cycles. The let-go currents for 114 men were: 15.5 milliamperes average, 9.7 milliamperes minimum, 21.6 milliamperes maximum. As

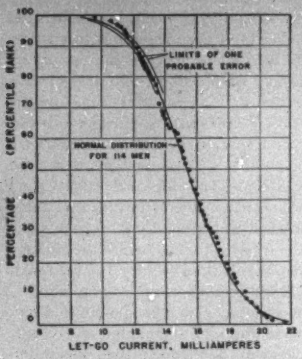

Figure 3. Distribution curve, 60-cycle let-go current

would be expected, the let-go current was higher for the huskier better-muscled subjects than for the thin, slight or lighter subjects. Right-handed men grasped the test electrode with the right hand, and left-handed individuals with the left. In the few trials that were made, the other or weaker hand had a limit of about 0.5 milliampere less than the test hand in the same subject.

Let-go tests were also conducted with direct current. Steady direct currents produced a sensation of internal heating of the hands and arms with only slight muscular contraction, although severe muscular contractions were produced by sudden changes in current magnitudes, and a severe shock was experienced each time the circuit was broken. Many subjects stated they would almost rather maintain contact in spite of the burning sensation than experience the shock produced when they released the wire. The values obtained in the tests were the maximum currents released and represent the limit of endurance rather than the let-go value. The limits of endurance for 28 men were: 74 milliamperes average, 61 milliamperes minimum, 83 milliamperes maximum.

SAFE ELECTRIC CURRENT FOR MAN

Several factors must be considered in deciding what constitutes a safe current for man. The victim of an accidental shock can often release himself by using muscles little affected by the current. The muscular reactions produced by the current may tend to break the circuit rather than to improve it, or loss of balance may free the victim. However, it is doubtful if any of these methods would be of avail when contact is established by gripping an electrified wire so that the path of the current is across the body. Naturally, when a man realizes his dangerous predicament, he will exert more effort to free himself than that stimulated in these experiments. Fright, however, might tend to nullify his efforts, and exhaustion certainly would. It was therefore concluded that the safe electric current for man is that value which can be released by using muscles directly affected by the current.

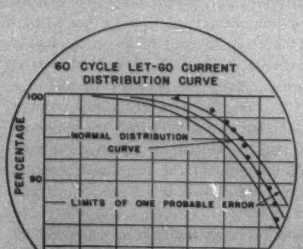

Figure 4. A magnified section of figure 3

The maximum current considered safe for man has been determined from a statistical study of the experimental results.[12] The curves of figure 3 show some of the results graphically. Obviously, the farther to the left one goes on the curve, the greater are the number of men who can release a given current. The conclusions are as follows: If it is assumed that the 114 men used in this experiment represent a cross section of all men of the same age and physical condition, then one man in 200 would not be able to let go of 8.8 ± 0.8 milliamperes or more current. This figure is based on a very conservative analysis. Having taken into consideration the factors mentioned, the authors are of the opinion that a reasonably safe 60-cycle alternating current for man is 8 to 9 milliamperes.

Steady direct currents produced much less severe muscular contractions than those produced by alternating currents. Within the range covered in these experiments, the physical endurance and will power of the subject fix the limit of the maximum release currents. Considering these factors, it appears conservative to conclude the maximum safe direct current for man to be at least 80 milliamperes.

For women and children the safe values for direct current and for 60-cycle alternating current may well be less, and in the interest of safety, no figures should be stated until adequate investigations have been made.

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Electric Utilities Under War Conditions

D. N. HEINEMAN

Some of the problems that beset utility operating and holding companies when war is in progress are described by an official of a European company with subsidiaries both inside and outside the war area; he also discusses the long-range planning which enable such companies to continue to function after the outbreak of war.

Courtesy British War Relief Society

THE INDEX of electric consumption for a given country often is regarded as a barometer both of the business trend and of the standard of living. But figures of the total demand for electric energy in a particular area and period throw little light on the economic situation. In the past 50 years, electricity has become a consumption good of primary necessity and consequently a commodity the demand for which is singularly inelastic. Moreover, when buying of consumers' goods is restricted, the decline in the use of electricity for domestic purposes may be largely compensated by an increased demand for the output of producers' goods. This shift has taken place in a number of European countries during the past few years.

In preparation for the present war, means of production were drastically diverted toward the manufacture of armaments and the procurement of what were regarded as strategic commodities. Remembering the difficulties that resulted during the previous war from a lack of various raw materials and foodstuffs, Germany, Italy, and Hungary, to say nothing of Soviet Russia, embarked on four-year or five-year plans, all aiming at national self-sufficiency in staple goods. The execution of such plans implies regimentation of production and consumption, both of which may be profoundly modified in volume and nature. Such changes react of course on the electrical industry, but electricity supply may not be greatly affected, because the demand is likely to be shifted from one group of consumers to another. An increase in the total volume of business will, of course, bring about a higher electric consumption.

In the countries that contemplated isolation during the war, the acreage under wheat was increased by about 30 per cent as a result of a series of "battles" led by their respective governments. At the same time efforts were made to promote the growing of vegetables and oil seeds, and to retain on the land, or to transplant from other areas, the labor required for augmenting production. In view of the enormous demand for men enrolled in military service a shortage of agricultural labor was inevitable; this was partly remedied by a wider resort to mechanization. Despite these endeavors the food problem seems to be solved only imperfectly in those countries, notably in regard to meat and dairy products, because of a marked deficiency of fodder and fertilizers formerly imported from overseas. In industry a higher degree of success has been achieved, and this implies a substantial addition to the normal demand for electric energy.

Take, for instance, Germany's war preparations. Ever since 1933 the economic system began to be directed toward a steady increase of the "*potentiel de guerre*"; yet a totalitarian economy was initiated only in the autumn of 1936, when the second four-year plan was announced at the Nurenberg party meeting. From 1935 to 1938 the output of iron and machinery rose by about 40 per cent, low-grade domestic ores being treated regardless of cost; the production of aluminum increased more than fourfold, exceeding that of the United States and Canada combined. The rise of about 53 per cent in electricity consumption is largely attributable to these developments. The manufacture of chemical substitutes for gasoline and lubricating oils has been furthered, again without regard to cost, and that of synthetic fibers probably will reach this year 300,000 tons. Rationalization has been ruthlessly pursued. Only the most efficient works were allowed to remain in

Based on an address delivered before the AIEE Philadelphia Section Philadelphia, Pa., October 14, 1940.

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operation. It is claimed that they are now working at 125 per cent of their theoretical capacity.

Similarly, in Italy iron and steel production largely has been centered in the mills of a single governmental holding corporation, which is producing at full capacity while its privately managed competitors are reduced to less than half their normal output, for lack of ore or scrap.

In both countries new approved investments have been encouraged by tax exemptions. In particular, the development of hydroelectric power stations has been furthered.

The anxiety to remedy a shortage of coal extended to private households and private commercial or industrial undertakings. An increase in the demand for electric heaters has been a feature in every country during the past few years; but in areas subjected to prewar or war conditions it was greatly accelerated. A sudden expansion in this demand might give rise to serious difficulties. For instance, it is estimated in Switzerland that the complete replacement of coal by electric energy for heating purposes would raise the annual consumption in that country from 7,200,000,000 to 24,000,000,000 kilowatt-hours. This danger has caused the authorities to limit both the purchase of electric household appliances and the private consumption of electricity.

In Germany, every form of demand for consumption-goods, including residential building, was—and is—restricted. Handicraftsmen and small retailers were driven into liquidation, partly with a view to increasing the labor force available to the armament industries or agriculture. The protection granted to labor under previous governments was withdrawn; hours were lengthened, women were pressed into service, and maximum wages were fixed without regard to variations in the cost of living. Choice of jobs was not only limited, but in many cases suppressed, workers being conscripted and allocated to the tasks for which they were most needed.

These conditions, together with a more and more developed system of rations and of prescribed uses for leisure, have altered the habits of the population in a manner that was bound to have repercussions on the consumption of electricity. The load-chart of the Berlin power stations shows a sudden and heavy drop at the times when the population gathers about the family radio or in the beer houses to listen to a speech from the Fuehrer.

Foreign trade also was affected by military preparations. Exports were furthered at the expense of home consumption, since it was urgent to procure raw materials that would be turned immediately into armaments or held in store for the outbreak of war. Imports were severely limited in the anxiety to husband foreign-exchange reserve. These foreign-trade policies have modified the economic situation in other countries, whose outlets were enlarged or diminished. In particular, political reasons or the attraction of barter facilities induced Germany and Italy to favor in their purchases the Balkan and South American countries to the detriment of Great Britain and the United States.

Germany's neighbors joined tardily in the armament race. Here also industrial output was increased under the pressure of military requirements. But in France, progress was hampered by a lack of labor that was only partly corrected when the 40-hour week was abandoned, after Munich. The French Government deferred industrial mobilization until the outbreak of the war, and rationing was scheduled to come into force at the end of May 1940. Yet conspicuous developments materialized during the years preceding the war in the hydraulic power stations and high-voltage lines of France, thanks partly to private initiative and partly to governmental action. In the United Kingdom remarkable progress in the enlargement and rationalization of electric production was achieved through the institution of the "grid system."

In considering what European electrical undertakings have done with the specific intention of preparing for war conditions, it is necessary to distinguish between operating companies and holding corporations.

So far as I know, the operating companies have taken no precautions against the danger of invasion or bombardment, nor have the authorities ordered any particular measures, except that some hydroelectric stations were directed to empty their water reservoirs when an attack appeared imminent, for fear of the lower neighboring regions being flooded if the dam were destroyed.

A power station standing in danger of being cut off from its habitual sources of supplies would, of course, be well advised to increase its inventories of fuel, spares, and other materials or equipment, but I have not heard of any European electrical or gas works having done so to any notable extent. Many European power plants are established within easy reach of coal fields; they saw no point in stocking fuel. They overlooked the possibility of a stoppage in the coal output. The power stations in the Paris area, for instance, held only a three-day stock of coal, relying partly on shipments from England and partly on supplies from hydraulic plants with which they are interconnected. The 240,000-kw Truyère hydraulic power station in central France contributes to feed both Paris and Marseilles, and is interconnected with Swiss and Pyrenese works, thus forming the turning plate of the electric distribution in a wide area of western Europe. However, the network of interconnections established in Europe, though no doubt very helpful under war conditions in the Netherlands, Belgium, and France, is not attributable to any anticipation of war. These interconnections were intended to be works of peace.

In spite of the development of the grid system in England, some minor power stations still survive in the London area. Although uneconomic and condemned to disappear in due course, they constitute today, in abnormal circumstances, a valuable stand-by should the large modern works be put out of operation.

Quite different from the situation of the operating companies is that of holding corporations responsible for the maintenance and progress of a number of associated companies, operating outside of the war area. An operating company has enough to do attending to its daily work. If there is a holding company to mother it, the latter will worry about more remote contingencies and provide for them. A large holding corporation, as these are conceived

in Europe, carries on staff work for its associated companies, which implies much careful forethought when war is threatening and watchful guidance when war is on.

Let me cite as an instance Sofina, the Belgian holding and service corporation with which I am particularly acquainted. Its associated electric and gas utilities operate in a number of European countries, in Argentina and Mexico, as also in Northern Africa. In addition, it holds minor interests elsewhere, including the United States. The annual output of the associated companies totaled over 7,500,000,000 kilowatt-hours in 1939, and their installed power (water and steam) totals between 3,000,000 and 4,000,000 kw.

Long before the present war started, we tried to visualize what might happen if Belgium were invaded and it should become impossible to supervise and assist from Brussels the operating companies entrusted to our care. We decided that we would retire to positions prepared in advance.

It is the task of a holding corporation to keep its subsidiaries provided with technical guidance, supplies, and funds. The preparation of offices outside Brussels was one of our precautionary measures. In August 1939 we formed a company in the United States that would be in touch with our overseas undertakings and provide for shipments of supplies and remittances of funds in the event of its being impossible to execute these deliveries from Europe. Considering that supplies of coal from Wales or the European continent might be unable to reach our power stations in Portugal or in the Argentine, we started as early as December 1936 stocking large inventories of coal at these stations. When war broke out, they had a good ten months' supply; our Argentine stations held over 600,000 tons of fuel. Regardless of the comparatively high freight rates of American coal, we placed orders in the United States for shipments to the River Plate. Our advisory and purchasing staff in the United States has been considerably increased since the invasion of Belgium.

On May 10, 1940, Brussels was awakened at dawn by the whistling and banging of bombs, one of which fell not far from our head office. A selected staff of Sofina was ready to start immediately, by car or by rail, for Ypres, Belgium, where, months before, offices had been prepared. We were at liberty to displace our seat of administration, as a Belgian Act of February 2, 1940, had expressly provided that in the event of war any Belgian company would be permitted to transfer its seat to a new location, inside or outside the realm, by a simple decision of its board of directors, acting through any two of its members empowered to that effect.

However, we very soon were compelled to vacate our Ypres office. Because of the influx of refugees, the call to the colors of every Belgian lad between 16 and 19, and the reports of the German advance, Ypres became an awkward place for studying enlargements of electric plants and perusing our companies' accounts.

This time our ultimate goal was Lisbon, Portugal. We had chosen this distant haven, not because we expected the whole of France to fall under the sway of invaders, but because, we feared that rigorous French regulations might make it difficult in war time to communicate with our associated companies overseas as frequently as would be essential. Besides, Sofina is largely interested in the Lisbon gas and electric utilities. Offices had been in readiness there since June 1939, and duplicates of accounting records, engineering files, and contracts were kept there. Yet we contemplated an intermediary halt in France in order to collect our refugee employees. For a few weeks we camped at Biarritz, with a mere outpost in Lisbon.

Getting out of Belgium and proceeding through France was not an easy job. There were passport troubles, and the roads were choked by interminable caravans of cars pathetically roofed with mattresses as a safeguard against short-range machine-gun fire from the air. Train services had broken down; our Ypres staff was scattered; but by hook or by crook, by car, lorry, and bicycle, they managed to reach Biarritz, some experiencing thrilling escapes.

When it became manifest that the French army was about to surrender, some of our senior officers went to Madrid, where they discussed with the Spanish authorities questions pertaining to our interests in Spanish companies. There we met with a most friendly reception; but our goal was Lisbon, to which city we moved a substantial body of our staff. All those officers and employees of our company who had left Brussels—numbering close to 200 with their families—successfully negotiated the visa barriers which have retained so many people in France against their will. A certificate attesting that such and such a person belonged to the staff of Sofina had, at the various frontiers, the magic effect of "Open, sesame."

Portugal today enjoys prosperity under an orderly and far-sighted rule. This small country is the lung through which continental Europe still can draw a breath of air from those parts of the world where speech and trade retain a measure of freedom. At present, Lisbon is about the only place in Europe where Sofina can remain in easy communication with its associated companies.

Thanks to the staff work described, our undertakings operating outside the invaded areas have been able to carry on their business as usual. But they have been affected, of course, by the changes which war conditions brought about in production and trade throughout the world. For example, the nationalist outlook has been accentuated in almost every country, and currency difficulties have increased the restrictions put upon importation and exchange transactions.

In connection with the holding company's obligation to provide funds to its operating companies, no clear-cut dividing line can be drawn between money remittances and deliveries in kind. For example, our operating companies in Turkey had considerable sums of money to remit to Belgium in respect of dividends; but payments in cash to Belgium were limited by a clearing arrangement; so we found ourselves compelled to collect our earnings in the form of live sheep and wheat, eggs and hazel nuts.

In the countries engaged in war, external commerce and money remittances are severely regulated even in regard to occupied or allied areas. Every home production useful to the prosecution of the struggle has been speeded up, while domestic consumption has been further curtailed.

The changes in the purposes to which electricity is applied and in the volume of the demand for each class of purposes have become even more marked than during the period of war preparations. In the United Kingdom, as well as in Germany, industrial mobilization is in full swing and has not been checked to an important degree by military operations.

To my knowledge, physical damage to electric plants is relatively small. Power stations, high-voltage overhead lines, and substations have been bombed. Presumably there have been hits in a number of instances. However, destruction caused by bombing would appear to be less serious than might be expected. Thus the power stations in Spain in which Sofina is interested were repeatedly attacked during the recent civil war, but attacks inflicted only slight damage on the thermic power plants, and did negligible harm to the hydraulic works and their transmission lines. Sabotage caused greater havoc.

Again, we have found that economic activities are likely to pick up with remarkable resilience after the cessation of active hostilities. In Catalonia, for example, the consumption of electricity is again approximately what it was in 1935, the year before the outbreak of the Spanish civil war.

This recovery is due in some degree to the substitution of electricity for gas as a result of a scarcity of coal; yet it contrasts with the persistent depression from which Spain is suffering, and supports the view already expressed that electric distribution is conspicuous among the industries that enjoy an inelastic demand. Having become almost as much a necessity as daily bread, electricity is hardly sensitive to the effects of cyclic or even of quite abnormal variations in the business trend.

For the time being, in the territories that Germany invaded, as also in the so-called unoccupied part of France, the much diminished purchasing capacity of the population, destruction of industrial plants, and a general disruption of trade will probably be reflected in a marked decline of electric consumption. In Belgium, I gather, operation was interrupted in some power stations when fighting was going on in the immediate vicinity. On the other hand, factories were obliged to close down when the Army mustered all its forces. Moreover, in a number of instances, steel works, cotton mills, collieries, and other undertakings of strategic importance voluntarily dismantled sections of their machinery in order to prevent operation under enemy control.

However, I hear that electric distribution has been resumed practically throughout the country. The bills go out to the customers as before, reduced in amount rather than in number. Sooner or later, electric distribution must assist in healing the wounds that war has inflicted, and the electrical industry should be one of the first to benefit from the recovery it will have helped to bring about.

Let us assume, as we confidently anticipate, that the world of tomorrow will not come under the sway of totalitarian regimentation, but rather will benefit from the lessons of this dreadful ordeal, and be free to shape a better order for mankind. Under war conditions an exceptional degree of government interference in private enterprise and private households is necessary, and consequently acceptable. We trust there will be a healthy reaction against the spread of state management as soon as this regimentation will have survived its usefulness. The preparation and prosecution of the present war have taught how production can be furthered and unemployment reduced, almost beyond belief, when the will of a nation is set in increasing the output of goods and services. We have also learned to what extent the available wealth can be increased by husbanding resources. A common ambition and a common fear have diminished the disintegrating forces of class hatred. This war has shown the constant need of planning well ahead, the strength of teamwork, the weakness of slipshod dispersion of efforts. It is likely to demonstrate the futility of attempts at national self-sufficiency.

We must guard against the danger that may rise from the spirit of national isolation, which is naturally fostered in years of strife and threatens permanently to set up new barriers in the way of international relations.

The works of the electrical industry are of peace; its task is public service. Utility men have a role to play in the preparation of peace for the day when the armed forces of evil shall be overcome. On a modest scale, utility companies with widespread interests are called upon to study and practice international co-operation, in tranquil as well as in troubled times. They learn acutely to realize the interdependence of nations.

It is absurd to believe that a community can fare better through restricting its choice of commodities or limiting the field within which it can render service. The world at large—mankind of today and generations to come—and each group of human beings in particular are the poorer for every obstacle put in the way of trade and friendly intercourse, for every ostracism decreed against men of a given religion or race.

The legitimate dread of "fifth columns" may cause responsible statesmen to look askance even at inscriptions in the columns of a business ledger. But international investments of capital, and the technical experience that usually is applied to the management of these investments, are equally beneficial to the country that invites or accepts foreign enterprises and to the country that enjoys this form of hospitality.

A large number and variety of international conferences sought to further the spread of knowledge. War has suspended these meetings. Censorships and enactments purporting to prohibit the reception of foreign broadcasts are curtailing the scope of mutual information. The world's distributing system of physical and spiritual wealth is pitiably disrupted, in a period when the means of exchanging goods and ideas are more highly developed than ever heretofore.

Humanity can never thrive in an air saturated with the poison gas that has spread over the greater part of Europe. The western European nations were unable to resist brute force; they enjoyed freedom but they lacked the spirit of collaboration. They were not prepared to face with an undivided will the onslaught of co-ordinated means of action applied by their enemies. Their weakness and its

causes afford a fearful lesson to all nations not enslaved.

The substratum of every conscious co-operation is mutual good-will. But good-will alone will not suffice. There must be agreement on some essential principles of political and economic government.

Let us recall the conditions under which an electric utility can best contribute to the public welfare: orderly liberty in initiative and association, helpful discussion for mutual understanding, the prudent building up of reserves against an hour of need, and a fair reward for reciprocal service. The same conditions would apply to every field of human activities. If widely and wisely ensured, I am confident that, figuratively speaking, their establishment would electrify the world.

Stevens Point–Minneapolis Coaxial Cable

THE first commercial installation of coaxial cable in the Bell System now is being completed between Stevens Point, Wis., and Minneapolis, Minn., a distance of approximately 200 miles. As may be seen from the accompanying illustrations, the cable contains four coaxial units in the center and an outer layer of 18 19-gauge quads. In the central space formed by the coaxial units are two 22-gauge pairs, and in each interstice between coaxial units is a hybrid quad made up of one pair of 19-gauge and one pair of 22-gauge wires; these are required for auxiliary service. The experimental cable installed several years ago between New York, N. Y., and Philadelphia, Pa. (*EE Jan. '37, p. 4–7*) contained two coaxial units and four pairs of 19-gauge wires.

The coaxial units of the new cable represent an improvement over those of the New York–Philadelphia cable. In the latter, the outer conductor consisted of a number of separate interlocking tapes; in the new cable, the outer conductor consists of a single tape which is formed into cylinder as it is pulled through a die, proper registry of the edges along the seam being obtained by the provision of projections or "teeth" along each edge of the tape. The tube so formed is held together firmly by a serving of steel tapes.

Before the details of design were decided upon, preliminary experimental cables with different modifications of construction were manufactured and thoroughly tested. In this preliminary work, it was found that a cable could be designed and manufactured with the necessary factor of safety to withstand at least as severe handling as is normally required in the factory and in the field.

In addition, the experimental structures also were tested for their electrical characteristics. The effective resistance and inductance were determined at frequencies up to 5,000 kilocycles to check calculated values. The dielectric constant of the composite coaxial unit was found from the test of capacitance and the known dimensions of the conductors to be about 1.1 at 5,000 kilocycles. Particular emphasis was placed on the test for conductance loss of the rubber disks. The increase in conductance with frequency and its change with temperature were determined over the range from 60 to 5,000 kilocycles. Test data showed that at 70 degrees Fahrenheit conductance increases approximately as the 1.08 power of frequency up to about 1,000 kilocycles, and as about the 1.02 power from 1,000 to 5,000 kilocycles. The dielectric strength became the subject of a somewhat extended investigation, and it was found that by careful removal of foreign material and projections from the surfaces of the center wire and copper tape, and thorough cleaning of the rubber disks, the dielectric strength could be improved sufficiently to permit a guarantee that the structure would withstand a d-c potential of 2,500 volts.

Concurrently with the evolution of the design of the coaxial conductor, transmission studies were clarifying the requirements a conductor should meet as a transmission medium. An extraordinarily high degree of impedance uniformity as compared with other types of circuits was found to be important. Since impedance uniformity depends upon mechanical and physical uniformity of the coaxial unit, great care was taken in its design and in the design and operating characteristics of the manufacturing equipment to assure a highly uniform product. In addition, special care was required in drawing the wire used for the inner conductor, and in rolling the tape for the outer conductor, in order to achieve the required high degree of mechanical uniformity.

Structure and cross section of Stevens Point–Minneapolis coaxial cable. Overall diameter is 1.7 inches; inside diameter of the coaxial unit is 0.27 inch.

Photos courtesy "Bell Laboratories Record"

Sun-Spot Disturbances of Terrestrial Magnetism

W. F. DAVIDSON
FELLOW AIEE

For many years magnetic storms at irregular intervals have been known to interfere seriously with the operation of electrical communication systems. The storm of March 24, 1940, however, considered to be possibly the greatest magnetic storm that has ever been recorded, not only interfered widely with communication systems, but also caused numerous interruptions in electric-power systems. The latter experiences are reviewed here, followed by some notes on current theories concerning magnetic storms.

ALTHOUGH communication engineers have long recognized the existence of magnetic storms or disturbances in the normal magnetic field of the earth, power engineers generally have not been aware of the fact that the storms could reach sufficient magnitude to cause operating disturbances in electric-power systems. Consequently, when on March 24, 1940, a number of power systems in the United States and Canada experienced operating difficulties coincident with the onset of a magnetic storm, the subject received widespread comment. The present discussion is a brief summary of power-system experience with some notes on the general subject of magnetic storms and the theories that have been advanced to explain them. For the latter, the author is indebted to Doctor A. G. McNish of the department of terrestrial magnetism, Carnegie Institution of Washington and particularly to the material he prepared for presentation before a recent meeting of the engineering committees of the Edison Electric Institute.[1] The information on power systems was obtained chiefly through responses to letters sent out by the Edison Electric Institute.[2] Valuable information on the effects of the storm on communication systems have been supplied by L. W. Germaine, long lines department, American Telephone and Telegraph Company.[2]

Power systems reporting disturbances are located in New England, New York, eastern Pennsylvania, southern and eastern parts of Minnesota, Ontario, and Quebec. On the ten systems on which disturbances were noted, the effects listed in the inverse order of the number of cases reported were:

1. Voltage dips ranging up to ten per cent, but generally of short duration (seven cases).
2. Tripping transformer banks by differential relay operation (five cases involving 15 transformer banks).
3. Large increases or swings in reactive kilovolt-amperes (four cases).

In addition, we have three separate observations:

1. Direct current was measured in a neutral grounding (one case).
2. Distortion of the current wave in a neutral grounding connection was recorded by oscillograph (one case).
3. A few blown transformer fuses on a 2,400/4,150-volt radial distribution system (one case).

No serious operating difficulties or interference with service were reported, possibly because it was Easter Sunday and loads were unusually light.

The instances of transformer tripping are probably of first importance because they present the largest potential possibility of interference with service. Examples are (eastern standard time throughout):

Two 75,000-kva transformer banks on the 220-kv system of the Philadelphia Electric Company–Public Service Corporation of New Jersey–Pennsylvania Power and Light Company, eastern Pennsylvania and New Jersey, tripped out by differential relay operation at 11:48 a.m. At about the same time, there were voltage swings of about $1^1/_2$ per cent and reactive power surges of about 20 per cent.

On the 220-kv system of the Niagara District, Ontario Hydro-Electric Commission, four transformer banks were tripped out by differential relay operation at 11:48 a.m.

On the 132-kv Abitibi system of the Ontario Hydro-Electric Commission, six transformer banks tripped out by differential relay operation at 11:48 a.m.

The 40,000-kva transformer bank connecting the 11-kv and 110-kv systems of the Narragansett Electric Company in Providence, R. I., were tripped out by differential relay operation. Shortly after this, an ammeter was connected in the transformer neutral and a direct current of 25 amperes was recorded. At the time of this observation, no operating difficulties were being experienced.

Two transformer banks operating from the 110-kv lines of the Central Maine Power Company at Bucksport were tripped out by differential relay operation at about 11:15 a.m. with accompanying voltage dips as large as eight per cent.

Some mention already has been made of reactive power surges and voltage dips. Other cases where these phenomena were observed, but without causing equipment outage, include the following:

On the system of the Northern States Power Company centering about Minneapolis, Minn., there was 105,000 kw of steam generating capacity in service in stations in the Minneapolis area and another 10,000 kw at Minnesota Valley, roughly 100 miles to the west. Two 10,000-kva synchronous condensers were operating in the Minneapolis area and one 5,000-kva synchronous condenser at Mankato about 100 circuit miles to the southwest. Transmission circuits involved were principally 69 kv with transformer banks generally wye-delta with grounded neutrals on the 69-kv side. In addition there are a few autotransformers connecting to the 115-kv system, these having delta-connected auxiliary windings. With few exceptions single transformers are used. The first disturbance in the nature of a surge as indicated by shift of load on the synchronous

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1. For numbered references see list at end of article.

condensers was observed at about 10:45 a.m. This was followed by numerous other surges at irregular intervals until 1:45 p.m. There was a slight recurrence of minor severity between 10:30 and 12:15 p.m. The most severe of the surges occurred at about 11:50 a.m. when the total build-up and decay period seemed to cover about four minutes. During that time the synchronous condensers which were operating on voltage regulators shifted load from maximum buck to maximum boost and return. There was an accompanying drop in voltage of about ten per cent. Considerable surges in reactive component on several of the circuits such as the Wissota-Oak Park 115-kv line where a change of 10,000 reactive kva was recorded. The graphic wattmeters showed no corresponding indication of the disturbances, and there were no circuit breaker operations. At Sparta, Minn., approximately 150 miles to the southeast of Minneapolis, the 69-kv line-regulation transformer operated to the extreme position in each direction and a lightning arrester discharge was noted.

On the Newburyport-Haverhill 22-kv double-circuit line of the Eastern Massachusetts Electric Company, the current was in the order of eight amperes, or about the charging current of the line, until late in the morning when the disturbances began. At that time swings to as high as 60 amperes or somewhat more than normal full-load current, were observed. Individual swings had a duration of a minute or less but recurred at frequent intervals over a period of some 10 or 15 minutes. There was considerable accompanying voltage drop.

On the Consolidated Edison 60-cycle system in New York, N. Y., a series of voltage disturbances took place beginning about 11:48 a.m. The first dip, which varied from 1½ per cent to 10 per cent in different parts of the system, was followed by a series of minor dips continuing at short intervals for a period of about one hour. The 25-cycle system voltage was not affected nor was there any appreciable change in system frequency or change in load in any part of either system. The voltage dips were of lower magnitude than those often caused by high-voltage feeder faults and did not have any serious effect on operation of customers' equipment or on the operation of the system. An analysis of available data indicates that on the 60-cycle system, the increase in reactive load was in the order of 45,500 reactive kva.

On the 110-kv system of the Niagara Hudson Power Corporation, there were numerous operations of an automatic oscillograph installed at Lockport, N. Y. A study of some of the records show that the neutral current has the characteristic wave form obtained with transformer operating with direct current superimposed on the alternating-current excitation, but since the oscillograph was operated through a current transformer, there was no direct observation of direct current.

The Boston Edison Company reported a considerable number of blown transformer fuses on its 2,400/4,150-volt radial distribution system. All were on transformers at the ends of feeders at points where the neutral was continued past open tie switches to feeders in adjacent areas.

For the purpose of explaining what happened in the power systems, I shall refer chiefly to the New York system, for which an extensive analysis has been made. It was noted that:

1. There had been voltage dips of short duration and considerable magnitude.

2. There had been increases in reactive kilovolt-amperes coincident with the voltage dips and proportionate to them.

3. There had been no appreciable change in the power components, that is, in kilowatt load.

These phenomena were, at least qualitatively, what would be expected if direct currents flowed in the windings of transformers so as to cause saturation and lead to increased a-c magnetizing currents.

H. B. Seeley of Consolidated Edison Company, has made a number of calculations in which he has used test data showing the effect of superimposed direct currents on transformer characteristics and has made the assumption of an earth-potential gradient of 10 volts per mile. He also used in his calculations the known electrical characteristics of typical feeders on the radial distribution system. The result is a calculated increase of 26.4 reactive megavolt-amperes compared with an observed 25—a convincing argument as to the validity of explanation.

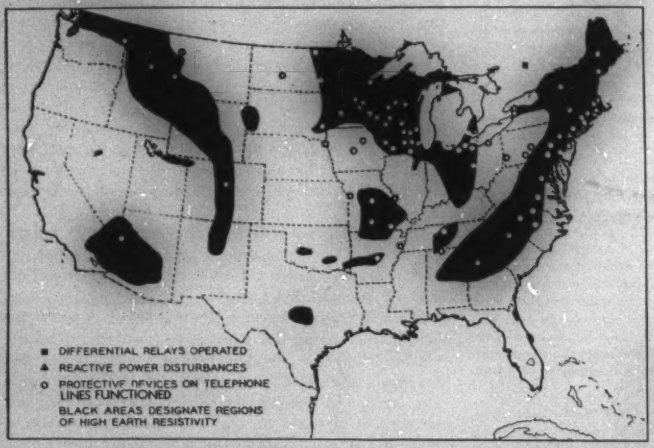
With this analysis in mind, we can explore some of the other cases, for example, the interconnected 69–115-kv system of the Northern States Power Company. The test data previously mentioned would lead one to expect that each ampere of direct current in the 69-kv windings of single-phase transformers would cause 75 reactive kva increase, and each ampere in 115-kv windings would cause 125 reactive kva increase in excitation. Assuming an average of these two values, it follows that only about 0.75 ampere of direct current in the neutral for each 1,000 kva of transformer capacity would be necessary to explain the observed increase of 30 reactive megavolt-amperes on about 400 megavolt-amperes of transformer capacity.

The disturbances in which transformer banks tripped on differential relay operation require no extended analysis. If direct current flows in one winding, it will not induce a corresponding current in the other, and in consequence single-phase transformers will have a steady magnetic flux in one direction which in turn will lead to saturation and increase the magnetizing component. The magnitude of this unbalanced component has been indicated in the previous discussion; for a 220-kv transformer one ampere of direct current will cause an increase of about 200 reactive kva in the magnetizing component, which appears as an unbalance at the differential relays. Coupled with this there will be a distortion of the wave form as indicated by the oscillograph. Insufficient data are available to permit making a statement as to the effect of this distortion on relay performance, but it seems probable that the effects will be generally in the direction of increasing the apparent sensitivity, thus further decreasing the amount of actual unbalance necessary to cause relay tripping.

Some thought has been given to the effects of direct currents on the ratio and phase angle of instrument transformers, but all of the test data so far examined suggest that the effects are of secondary importance. Instrument transformers generally operate at comparatively low magnetic flux densities, and in consequence they are far less susceptible than power transformers to the disturbing effects of superimposed direct currents. Relatively large d-c components are necessary to make a five per cent change in ratio of current transformers or to cause a similar error in the ratio of potential transformers.

In seeking further light on the underlying phenomena involved in the magnetic storm, we may next turn to the data collected by the Bell Telephone system. Like the telegraph companies, telephone companies have long been aware of magnetic storms and have taken steps to place

instruments so that records of their currents could be observed. Many recording voltmeters are in continuous operation connected between ground points at various central offices. From an analysis of their records, it is known that potential differences of 400 volts or more occurred between numerous line terminals. One of the most serious effects of these disturbing voltages was the operation of the protective devices installed in central offices at the juncture of open-wire and cable plant. In numerous cases, the voltages continued at such high values that the protective devices operated as fast as they were closed, making it impossible to use the circuits.


■ DIFFERENTIAL RELAYS OPERATED
▲ REACTIVE POWER DISTURBANCES
○ PROTECTIVE DEVICES ON TELEPHONE LINES FUNCTIONED
BLACK AREAS DESIGNATE REGIONS OF HIGH EARTH RESISTIVITY

Observed disturbances on communication and power lines in United States and southern Canada caused by magnetic storm of March 24, 1940

In other cases, intermediate discharges across the gap of the protective devices were so frequent and severe as to make the circuits noisy and not satisfactory for service.

Analysis of the data obtained during this particular storm confirms earlier observations which show that the largest potential gradients occurred in areas known to have high earth resistivity. It may be observed that these areas are the same ones in which power-system disturbances were noted.

Coming now to the matter of a more fundamental explanation of the nature of the magnetic storms, we find that we enter a field of speculation in spite of the enormous mass of exact scientific data that has been accumulated during the past century or more. For many years, magnetic observatories distributed throughout the world have been accumulating information on the earth's magnetic field. From these it is known that there are continual changes not only from day to day but from hour to hour; usually these changes are so small as to produce no noticeable effect even in communication circuits with earth return. However, during the periods of magnetic storm, the changes become very much greater. Some idea of their magnitude may be gained from Doctor McNish's calculation that during the great magnetic storm of April 1938, energy was expended at the rate of 2,000,000,000 kw for a two-hour interval. The storm of two years later appears to have been even more intense so it is not surprising that there were effects even on power systems of 2,000,000 kw connected capacity.

To quote now from Doctor McNish:[1] "Mathematical analysis has shown that field changes during magnetic storms are due principally to causes above the earth's surface, presumably electric currents, and that these external effects are accompanied by effects due to the induction of currents within the earth by the primary external fields. It is an unfortunate limitation of mathematical analysis that it cannot describe uniquely both the location and configurations of these external currents, although with the assistance of mathematical analysis and some other considerations one may deduce probable locations and configurations. The field changes may be divided into two classes—those which are symmetric about the earth's magnetic axis and those which are nonsymmetric. The first class may be thought of as due mainly to a large ring current about the earth, like the rings of Saturn, or to a current flowing in the outer atmosphere with intensity varying as the cosine of the geomagnetic latitude from zero at the geomagnetic poles to a maximum at the equator. The inferences we may draw from magnetic observations are entirely ambiguous in this regard for they permit either possibility. If the ring current is the correct conception its radius may be several times that of the earth. During the first phase of a magnetic storm the current in this ring flows from west to east and during the main or second phase it flows from east to west; the magnitude of the current reaches several million amperes at its maximum during great magnetic storms. Although the greater part of the energy of magnetic storms is involved in this hypothetical ring current, the magnetic changes are not rapid enough to

induce the very high potentials within the earth which play havoc with electric systems.

"The second class of field changes, which are nonsymmetric about the earth's geomagnetic axis, are associated with electric currents flowing with maximum intensity along the auroral zone. There is every assurance that these currents are confined to our atmosphere, probably at a height of about 100 kilometers or so, where radio observations and auroral phenomena attest that the atmosphere is highly ionized. Field changes arising from these currents are responsible for the effects on communication and power lines.

"Observation of the field changes at a number of stations during various magnetic storms has permitted mapping of typical current-circulations. In general, these consist of intense currents flowing in an east–west direction along the auroral zone with diffuse return circulations—also confined to the atmosphere—across the polar cap and in low latitudes. Westward currents predominate on the morning side of the earth and eastward currents on the afternoon side, the westward currents being in general more intense. Such currents may continue for an hour or several hours but rapid changes in their intensity take place. Obviously, with such a distribution of currents, although a magnetic storm may be occurring all over the earth, certain places will be subject to more intense disturbance depending upon the location of the place and the time of day at which the magnetic storm began. The strength of these auroral-zone currents may exceed 1,000,000 amperes and changes exceeding 100,000 amperes in one minute have been observed. Although the path may be 100 miles or so in width, to a first approximation it may be regarded as confined to a vast trolley-wire stretching for hundreds of miles in an east–west direction at a height of about 100 miles above the earth.

"The cause of the primary electric currents in the outer atmosphere or about the earth remains a matter of speculation. We know definitely that solar activity is directly responsible for magnetic storms—magnetic storms vary in frequency with the sun-spot cycle and exhibit a quasi-periodic effect which is associated with the sun's rotation."

Finally, a word as to "what to do about it." The record of past years indicates that while there will be recurrence of magnetic storms of great magnitude, their effects probably will be no greater than just described. What the effects on service might be is for others to say. Possibly they are serious enough to justify a review of differential relaying to determine whether changes can be made that will reduce the sensitivity as steady d-c components in the neutral increase.

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Developments in Resistance Welding

R. T. GILLETTE

A survey of the recent developments that have given resistance welding its present importance in high-speed industrial production

IT IS well known that the first resistance welder was conceived and built by Doctor Elihu Thompson early in 1886. While this welder was crude and of low capacity, it demonstrated that the basic principles of resistance welding were sound and of great value to the fabricating industry. Although the first welder was a butt welder, the other types of resistance welding—spot, projection, seam, butt-flash, percussion, and modifications of each—were soon developed from information obtained from the early work done on the first few machines.

The early resistance-welding machines were mostly manually operated and timed and were capable of making only a few welds a minute. A machine rated at 25 kva was considered quite a large machine.

With the development of high-speed production methods in the automotive industry, followed by the same methods in many other industries, resistance welding rapidly attained a major position in many types of metal fabrication. Welding machines were constantly improved until at present they compare favorably with the best type of machine tools. The electrical capacity also has increased rapidly, so that resistance welders of 200 kva to 500 kva are very common and welders with capacities as high as 5,000 kva have been built and are in operation.

A brief description of some of the more recent developments might be of interest. To avoid confusion, it will be advantageous to treat the developments separately.

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1. For all numbered references see list at end of article.

CONTROLS

The control of time of current application on the early resistance welders was very inadequate, but with low-capacity welders working mostly on low-carbon steel acceptable results were obtained. Most of the earliest controls were simple pass-through switches operated by the foot pedal of the welder, which closed the switch as pressure was applied to the part to be welded. A further movement of the foot pedal opened the switch. By this method the operator controlled the time of current flow. Obviously the timing was very erratic. This type of control with some modification was used on all types of welders. As motor or other mechanical drive was applied to welding machines, cam-actuated limit switches operating solenoid contactors became the common method of current control. These were an improvement over the straight manual control but still had several deficiencies. The gap in the contactor changed rapidly, due to main contacts wearing. Maintenance costs were high and the switching was nonsynchronous.

At about the same time, seam welders were equipped with mechanical interrupters of various types. In some cases these interrupters were driven with synchronous motors in an attempt to get interrupters to operate without flashing. These devices, however, were difficult to keep in operation because of wear of parts and change of power factor on the welding machines, and about 300 interruptions per minute was the maximum speed at which they could be operated. At this time the electronic control with its fully synchronous switching was developed. Figure 1 shows a combination control used for spot, projection, pulsation, and seam welding. At about the same time many steel alloys, including the stainless steels, were being developed and put into production. Also, the use of resistance welding for fabricating the nonferrous metals and alloys was growing rapidly. Very short welding times are required for fabricating these metals and the electronic control was particularly adapted to this work.

It is also well known that the current applied to a welding transformer at a point on the wave earlier than the power-factor angle will cause a transient condition that may give several times the normal current for a short time. This transient condition soon was discovered to be more serious than a small variation of time, as is indicated by oscillograms showing synchronous and nonsynchronous switching (figure 2). One of these transients may actually burn a hole through the work piece.

The use of these fully synchronous electronic controls gives an accuracy in control never obtained with any of the mechanical devices. They are particularly adapted for use as seam-welding interrupters due to their accuracy in always switching on the proper point of the wave to eliminate transients, and the speed can be anything up to 1,800 per minute, or one cycle on and one cycle off on 60-cycle current. They may also be used as current or heat regulators by firing at various points on the voltage wave, thus using only part of each half-cycle. This is shown by the oscillograms in figure 3. This method may be used alone or to supplement the standard tapped transformer.

Electronic control is available in all sorts of combinations for any type of resistance-welder control.

Supplemental to the development of the fully synchronous completely electronic control, many other types of

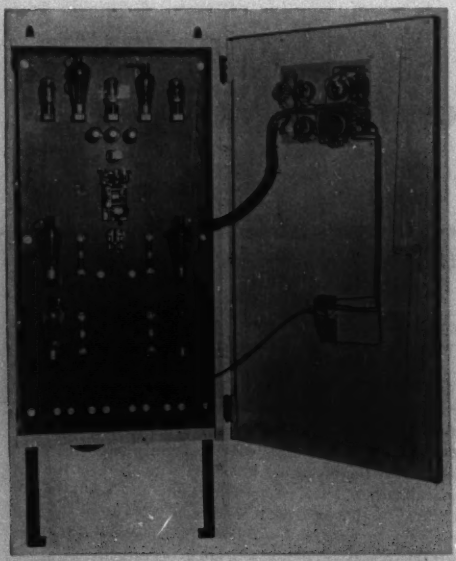

Figure 1. Front view, with door open, of enclosed Thyratron control panel for spot, pulsation, and seam welding, 220, 440, or 550 volts, 60 cycles

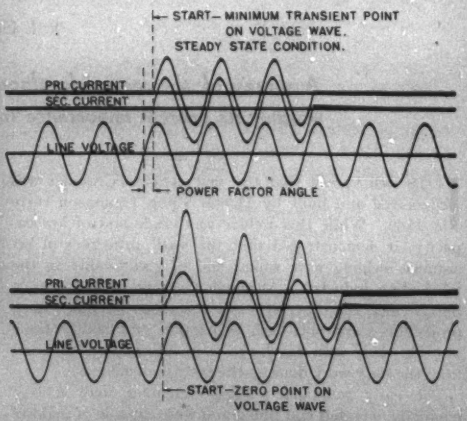

Figure 2. Oscillogram of line voltage and currents in welder transformer, showing results of starting current flow at different points on the voltage wave

control have been developed—some partly electronic and partly mechanical and others entirely mechanical—for use on motor-driven welders, as well as sequencing controls for air-operated welders which sequence and time the lowering of electrode, time of current dwell, squeeze time, and raising of electrode. These various types of control are cheaper than the complete electronic control, which perhaps is their chief recommendation. However, they do fill a need for a relatively cheap control where the ultimate in speed and quality of product is not the principal consideration. All the recently developed controls are much better than those used only a few years ago.

The development of accuracy in controls, and the use of very short times in welding, have radically affected the design of welding machines. The movable parts must be built as light as possible to reduce inertia to a minimum, so that the electrodes will follow and push up the weld and not lose contact and cause arcing in the weld area. Friction in the welding machine should be kept as low as possible for the same reason.

The electrical capacity in many of the new types of welding machines is higher than that of the older machines in order to deliver enough energy in the very short welding times now used. Many welds are now made in from 1/2 to 3 cycles on 60-cycle power, while many of the old machines used more than as many seconds.

POWER SUPPLY

Considerable work has been done to develop ample power supply with low voltage drop to supply the single-phase high-current intermittent power used on the larger sizes of welders.[1] The use of series capacitors for power-factor correction is also a recent development.[2]

PROTECTIVE DEVICES

The usual procedure on resistance welders is to ground one side of the secondary circuit, but this is not possible in some special machines. In such cases the secondary circuit is grounded through a modified Thyrite lightning arrester which grounds at approximately 50 volts.

A good type of air circuit breaker is also used in many cases to protect welding machine and line from short circuits and overload.[3]

MEASURING INSTRUMENTS

It is many times of great value to be able to measure as a permanent record the current used to make a weld, or to be able to duplicate a certain welding setup in some other place than the one in which it was first used. An oscillograph of course can be used but requires considerable time and skill and also is expensive when used in production. A newly developed instrument called a stop-pointer ammeter is of considerable value for this work.[4]

A somewhat different method of measuring welding current has been described by Hess, Wyant, and Muller.[5]

A cycle recorder has also been developed to record the actual number of cycles used in a weld. This is of value for checking timing of welds, making records for inspection purposes, and for other uses.

A weld recorder is available that records amperes-squared seconds. Where very high quality is required, this instrument records the conditions of current. During the weld time it is sensitive to line voltage, variation in timing, and any other factors, such as condition of material and electrode maintenance, that affect time or current.

(a) (b) (c)

Figure 3. Oscillograms of current in welder, using phase-shift method of heat control by means of Thyratron welding controls. The top curves show primary current, the middle curves secondary current, the bottom curves line voltage

(a)—Minimum heat (approximately 8 per cent)
(b)—Moderate heat (approximately 55 per cent)
(c)—Maximum heat (100 per cent)

SPOT WELDING

Spot-welding equipment has been developed rapidly in the last few years along several lines. Although the press-type welder making one spot at a time is still standard, where many spot welds are to be made on rather large complicated assemblies, several types of hydraulically operated multiple-electrode machines have been developed.

One outstanding type uses a frame designed to act as an assembly fixture, with each electrode mounted on its individual hydraulic cylinder. The assembly to be welded is mounted in the machine; then all the electrodes are brought into their pressure position and act to clamp the work. Each electrode is electrically connected to a common transformer, through a straight-line commutating device, combined with an electronic timer; the current is turned off while the brush is traveling from one commutator segment to the next; and an auxiliary contact energizes the electronic timer for a definite time. In this manner, spot welds are made in rapid succession with all electrodes under pressure. These welders have great flexibility of operation and can be built for many types of structures. The fact that all electrodes are held under pressure while the welds are being made tends to reduce distortion to a minimum. Machines of this type have been built with more than 100 welding stations.

For spot-welding aluminum and its various alloys, two types of equipment have been developed. One type, developed by Sciaky of France, has found quite wide application in the United States. It uses stored magnetic energy in the welding transformer. This energy when collapsed gives a high secondary-current impulse of short duration with a steep wave front. Some machines of this type also use a variable pressure cycle during the welding time. Starting with high pressure, the pressure is reduced while current is flowing, then increased again to give extra

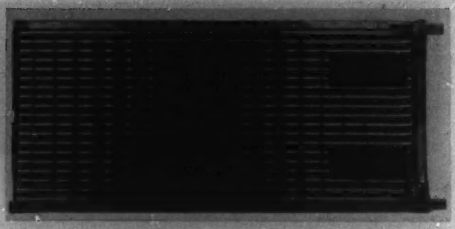

Figure 4. Condenser for one type of refrigerating machine, fabricated by resistance welding

forging action at the end of current flow. This type of equipment seems to be finding considerable use in aircraft factories.

The American-made counterpart of this machine stores the energy electrically in a bank of capacitors. These capacitors are charged through a three-phase rectifier, then discharged through the primary of a special transformer which again gives a unidirectional current with a very steep wave front. This machine may or may not use the variable pressure cycle.

The results from these two methods of welding aluminum alloys seem to be quite comparable.

PULSATION WELDING

Pulsation welding,[6] in which the current is supplied in several increments rather than continuously, has been improved in its application to spot welding. Applying the current intermittently allows water-cooled electrodes to dissipate their heat during the off-current time, giving longer electrode life. It also allows better heat distribution when spot-welding heavy material. This method has been used for welding material of thickness ranging up to that of two pieces of one-inch steel.

Details of the pulsation method of welding were published in a serial article by H. C. Cogan and Ralph S. Pelton in the *Welding Journal*.[7] The use of fully synchronous electronic control is essential for the satisfactory application of pulsation welding.

PROJECTION WELDING

A modification of spot welding in which the current is localized by projections on the work pieces, instead of electrodes with a reduced section end, is finding increasing applications. This method permits using electrodes of large section faced with the new hard electrode materials, giving lower maintenance costs and better quality work. It also allows making multiple welds in one operation on condensed sections where spot welding cannot be conveniently used and simplifies the problem of jigs and fixtures, thus lowering fabricating costs.

SEAM WELDING

The development of fully synchronous electronic control has made possible many outstanding developments in seam-welding equipment. A typical example is the seam welding of a refrigerator condenser (figure 4). These condensers have 900 inches of weld and first were welded on the old standard seam welders (figure 5), which produced an average of $3^1/_2$ condensers per hour.

After several steps of development, a very successful ten-wheel seam welder was produced. This machine has five transformers, each rated 200 kva, with two welding wheels to each transformer, on top of the work, and a special copper-alloy shunting platen below the work, making two seam welds in series. It is equipped with five fully synchronous electronic control panels, including phase control for heat regulation. The continuous rms load on this welder is approximately 1,050 kva and its production is from 60 to 65 condensers per hour. At an estimate of 60 per hour, it makes over seven miles of seam weld every eight hours, or, considered as single overlapping spot welds, 4,320,000 spot welds every eight hours.

Where long rows of equally spaced spot welds are made, it is frequently possible to make them on seam welders. For one such application, requiring several hundred spot welds per assembly, a seam welder with two transformers and four welding wheels (figure 6) is used with the electronic control set with the off-time long enough to make 7 welds in two inches instead of a continuous seam. This welder makes spot welds at the rate

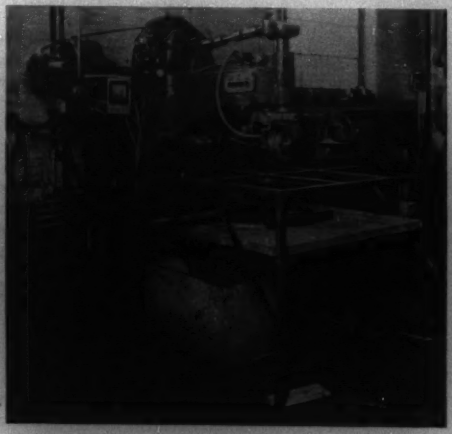

Figure 5. Line welder for developmental work

of 2,400 per minute. These are only examples of many such developments in the United States.

BUTT WELDING USED PRIMARILY FOR NONFERROUS METALS

The development of butt welding is proceeding almost as rapidly as that of other types of welding. Fully automatic butt welders are in operation for welding copper bull wire with diameters up to one inch for continuous lengths to draw into fine wire. These have fully calibrated dials to make possible rapid setup for various sizes of wire.

With these calibrations it is possible to change from one size of wire to another in a fraction of a minute and obtain satisfactory results without testing welds each time.

COPPER ALUMINUM BUTT WELDS

In many cases it is desirable to wind coils of aluminum for weight reduction. To facilitate assembly it sometimes is necessary to weld copper ends on the aluminum coil. These joints must be made by a special procedure to exclude brittle aluminum alloy from the joint. This procedure is explained in the patent for the process[8] and also in a previous article by the author.[9]

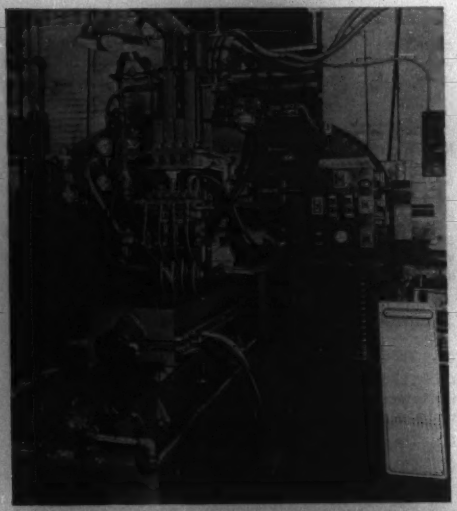

Figure 6. Front view of four-roll series seam welder with full automatic control, for intermittent seam welding of refrigerating-machine evaporators

FLASH BUTT WELDING

Flash butt welding is used primarily for ferrous metals and alloys. The developments in flash welding probably have been mechanical rather than electrical, and have been aimed toward higher-speed production and more completely automatic processes, to eliminate the human element.

Some outstanding flash welders have been built to weld the wide sheets in continuous strip steel mills to make continuous lengths for pickling and rolling. Some very high-speed flash welders have been built for the automotive and steel-barrel industries.

PORTABLE OR GUN WELDERS

Some of the recent developments in the use of portable or gun welders are of particular interest to the electrical industry, as material of thickness ranging up to that of two pieces of three-eighths-inch steel is being fabricated by the use of pulsation welding with gun welders. All sorts of steel structures for frames, enclosing structures, and others for electrical purposes are being made by portable welders equipped with fully synchronous electronic control.

ELECTRIC SILVER-ALLOY BRAZING

The use of all types of resistance-welding equipment for brazing brings to brazing work the same degree of accuracy that is achieved in welding.

A great many parts made of copper that do not lend themselves to welding may be brazed with standard resistance welders equipped with accurate control and using tungsten or carbon facings on the electrodes.

Portable equipment for incandescent carbon brazing of wire and cable joints is also available. This type of equipment is capable of brazing joints in electrical conductors very rapidly and usually much more cheaply than they can be brazed with a torch or soft-soldered. These joints are more permanent than the soft-soldered joints and will stand much higher temperatures.

The use of resistance welding is growing very rapidly, as is shown by the following figures prepared by the Resistance Welding Manufacturers' Association.

Year	Approximate Kva Sold
1938	158,341
1939	189,885
1940 (to August 31)	232,006

In addition, considerable equipment also is being built by some of the larger users of resistance-welding equipment.

The new resistance welders as built today are precision-type machine tools and should be operated as such.

With the correct selection of welding machine and control, competent supervision, trained operators, proper selection of thoroughly cleaned material, and careful design of parts to be welded, a high-quality product can be achieved by welding at a cost as low as or lower than that of any other method of fabrication.

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Three-Phase Systems With Unbalanced Wye-Connected Loads

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The various methods of solving three-phase unbalanced wye circuits, usually found separately in engineering literature, have been brought together here; each is illustrated by a specific example

WHILE methods for solving unbalanced systems have been in use for many years, applications and extensions of various forms of circuit analysis continue to appear. Evidence of this is given by the recent discussions in the "Letters to the Editor" columns of ELECTRICAL ENGINEERING on the unbalanced wye-circuit.[1,2,3,4] Such discussions serve the very useful purpose of rounding out fundamental theory of the profession, and are of particular significance in the educational field where the attack on circuits first takes place. The discussions are of value in any of several ways: by adding to generalizations on existing forms of solution, by clarifying general methods, by illustrating certain approaches through specific example, and by simplifying the actual work required in handling a problem.

There is no one place, however, where one can find these many forms of solution grouped together. Textbooks are perhaps the best references for them, but any one textbook will contain only one or possibly two methods. Many books entirely omit treating unbalanced systems, or discuss the unbalanced delta circuit with no reference to the unbalanced wye.

The purpose of this article is to present in one place the applications of the many methods available in solving the three-wire unbalanced wye-circuit, and to illustrate each mode of solution by a specific numerical example. The article should have value in the field of education, and the following discussions should be of interest to students and instructors in their class work on circuits. In addition, however, the treatment should be of considerable value to the many in practice who occasionally meet with and must solve the type of problem described here. Although the attempt in practice almost always is to balance a system as nearly as possible, yet there are times at which a circuit is sufficiently unbalanced to require handling as such. There are also special circuits used in testing which are unbalanced wyes. One type of phase-rotation indicator, and the monocyclic circuit converting constant potential three-phase to constant current single-phase, again are examples of unbalanced wye-loads met in practice. To the writer's knowledge this article includes all the major methods that have been given in the past, in published form, for the unbalanced wye. The unbalanced delta is essentially a treatment of individual single phases, and since the approach to it is well known this type is not discussed.

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1. For all numbered references see list at end of article.

STATEMENT OF THE PROBLEM

Briefly stated, the usual conditions surrounding a problem on unbalanced circuits are:

(*a*). A known set of impedances, or loads, and their circuit arrangement. The impedances may be unequal to each other in magnitude, in power factor, or in both.

(*b*). A known three-phase supply. Usually the three line-to-line voltages are given, normally balanced. They may, however, be unbalanced in magnitude and in phase.

From these data one may wish to determine any one or several of the following quantities:

(*a*). The line (or phase) currents.

(*b*). The line-to-neutral voltages, or the residual voltage which exists between the common junction of the load elements and the neutral of the supply system.

(*c*). The system power.

(*d*). Phase relations between certain voltages and currents.

The circuit conditions for illustrative examples are given in figure 1 which shows an unbalanced wye-connected load receiving power from a three-wire three-phase supply. The line voltages are taken as 100 volts, and, with the ohmic values of the circuit elements, are chosen arbitrarily to give convenient magnitudes and phase angles in examples which appear later. These values are, however, fully representative of any such unbalanced system. Let the problem first be that of determining the line currents. From these any other desired information readily follows.

METHODS OF SOLUTION

The many methods of solution for the circuit of figure 1 are:

(*a*). Calculating line currents directly from a system of simultaneous algebraic equations.[5] Each line voltage is written as the sum of the impedance drops of the two phases between those lines.

(*b*). Expressing the phase voltages, and hence the currents, in terms of two unknown scalars in quadrature[6,7] which are evaluated first. The currents follow directly.

(*c*). Calculating the residual voltage from the known line-to-neutral voltages of the supply and the impedances, or admittances, of the load elements.[5,6,8,9,10] The phase voltages of the load follow, and then the currents. There are variations in this method.

(*d*). Calculating the line-to-neutral voltages directly in terms of the line voltages and the impedances, or admittances, of the load

elements. This scheme is an extension of method (*c*), both arising from the same system of equations.

(*e*). Superposition.[9] The current distribution in the load elements is found for each generator phase voltage taken separately, the phase current being the sum of these components.

(*f*). Symmetrical components.[5,7,9,11] The phase currents are expressed in terms of two balanced current systems of opposite phase sequence.

(*g*). Wye-delta transformation[3] in which the original wye-load is replaced by an equivalent delta-connected set of impedances. The problem then is solved in the conventional way for the delta circuit.

ILLUSTRATIVE EXAMPLES

Each of these forms of solution now will be applied, in the order given, to the problem presented by figure 1. Since too many details often detract from the clarity of a presentation, in general only one current will be calculated the others being determined in like manner. Again, certain apparent and indicated intermediate algebraic steps in handling a problem are left to the reader. One usually derives much value from a discussion by carrying out some of the development and calculation himself.

Standard (counterclockwise) rotation of all vectors is used, and for reference at the start, let

$Z_A = 10/\underline{30} = 8.66 + j5$ ohms $\qquad Y_A = 0.0866 - j0.05$ mhos

$Z_B = 10/\underline{-60} = 5 - j8.66 \qquad Y_B = 0.05 + j0.0866$

$Z_C = 10/\underline{0} = 10 + j0 \qquad Y_C = 0.1 + j0$

and the voltages be

$E_{NA} = 0 + j57.74$ volts $\qquad E_{AB} = 50 - j86.6$ volts

$E_{NB} = 50 - j28.87 \qquad E_{BC} = -100 + j0$

$E_{NC} = -50 - j28.87 \qquad E_{CA} = 50 + j86.6$

These quantities appear constantly in the following developments and hence are available at this place for ready substitution. E_{BC} has been chosen along the horizontal axis, but it is realized, of course, that either of the other two line voltages could have occupied this position. The diagrams of connection and of voltage, both shown in figure 1, are two entirely different things, although at times it is helpful to some if they are similar in appearance.

The subscripts associated with voltages and currents are merely schemes of notation to be followed in obtaining magnitudes and proper phase angles of these quantities. Just so long as the same conventions and interpretations apply to all similar quantities, the scheme of notation is immaterial. Let us assume here that E_{AB}, for example, means that the direction of positive voltage is from A to B. In consequence of this,

$$E_{BA} = -E_{AB}$$

since E_{BA} is taken in the opposite sense of direction. Any phase voltage of the load, say E_{OA}, then is positive outward from the common junction. The relation between line and leg voltages is such that, for example,

$$E_{AB} = -E_{NA} + E_{NB} = -E_{OA} + E_{OB}$$

In adopting a convention for current flow, let the positive direction in the lines be from supply to load. This is the direction of energy transfer. Currents then are positive outward from the supply neutral, and at the load are positive inward toward the junction. Obviously, conventions are arbitrary and positive current flow could be taken in the direction of O to A. At most a change in convention only reverses all voltages, or all currents, by 180 degrees on the final vector diagram for the complete system.

Method (*a*). Applying Kirchhoff's laws to the load circuit of figure 1, we may write

$$E_{AB} + I_A Z_A - I_B Z_B = 0 \tag{1}$$

$$E_{BC} + I_B Z_B - I_C Z_C = 0 \tag{2}$$

$$E_{CA} + I_C Z_C - I_A Z_A = 0 \tag{3}$$

and

$$I_A + I_B + I_C = 0 \tag{4}$$

Since any two of the voltage equations will yield the third, the four equations really constitute a set of three which involve the three unknown line currents.

Let I_C be desired. From equation 4, I_A is expressed in terms of I_B and I_C and then is eliminated from equation 3.

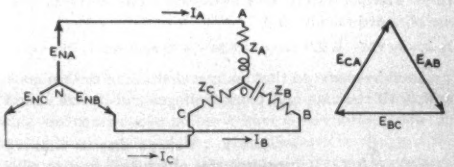


Figure 1. Unbalanced wye-connected load receiving power from a three-wire three-phase supply

This new voltage equation, and equation 2, are then solved simultaneously for either I_B or I_C, whence

$$I_C = \frac{E_{BC} Z_A - E_{CA} Z_B}{Z_A Z_B + Z_B Z_C + Z_C Z_A} \tag{5}$$

The intervening algebraic steps are elementary and direct, and therefore are omitted. Substitution of the complex quantity magnitudes for these voltages and impedances gives

$$I_C = -6.51 - j4.77 = 8.07 \text{ amperes}$$

The other currents are found in like manner.

This method is as straightforward as any. Whatever disadvantage it possesses is inherent in all calculations involving complex quantities—an error in sign or magnitude at times being hard to locate.

It might be remarked at this point that although but one current, equation 5, is given in symbolic form, the others can be written from this one by inspection. One has but to note the cyclic order and appearance of the subscripts of the quantities concerned. These same statements hold for other current and voltage equations that are to appear.

Method (*b*). Let the neutral point O of the load be shown as in figure 2. Its exact location is not yet known, of course, but it may be assumed at any position for the

time being. With point A as a reference, the three phase voltages are

$$E_{OA}=-a+jb$$
$$E_{OB}=(50-a)-j(86.6-b) \qquad (6)$$
$$E_{OC}=-(50+a)-j(86.6-b)$$

whence the currents become

$$I_A=\frac{E_{OA}}{Z_A}=\frac{-a+jb}{8.66+j5}=-0.0866a+0.05b+j0.05a+j0.0866b$$

$$I_B=\frac{E_{OB}}{Z_B}=\frac{(50-a)-j(86.6-b)}{5-j8.66} \qquad (7)$$
$$=10-0.05a-0.0866b-j0.0866a+j0.05b$$

$$I_C=\frac{E_{OC}}{Z_C}=\frac{-(50+a)-j(86.6-b)}{10}=-5-0.1a-j8.66+j0.1b$$

Since the sum of the currents is zero, the sum of the real components must equal zero, and so also must the sum of the imaginary components. Thus,

$$-0.2366a-0.0866b+5=0$$
$$-j0.0366a+j0.2366b-j8.66=0 \qquad (8)$$

from which $a=15.10$ and $b=38.95$. The currents now are obtained readily, and

$$I_C=-5-1.51-j8.66+j3.90=-6.51-j4.76 \text{ amperes}$$

It will be observed that upon evaluation of the scalars a and b, all currents and phase voltages can be calculated

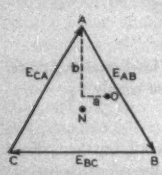


Figure 2. Voltage diagram showing co-ordinates of assumed floating neutral, point O

immediately. Also, these scalars locate the neutral point O. The shift from its position N, under balanced conditions is

$$E_{NO}=15.1+j18.8 \text{ volts}$$

N is, of course, at the geometric center of the triangle of line voltages.

While point A has been chosen as reference, any other reference point could just as well have been selected. Were N to have been the reference position, a and b then would give in themselves the shift of O from N, that is, $E_{NO}=a+jb$.

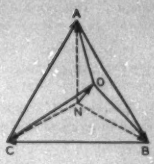
Method (*c*). As in the previous method, let O be chosen at any point. On such an assumption, figure 3 thus shows the complete voltage diagram for the system. The actual phase voltages are E_{OA}, etc.; the phase voltages for balanced loads are E_{NA}, etc.; and the residual voltage, or shift of the neutral, is E_{NO}.

By aid of figure 3,

$$I_A=\frac{E_{OA}}{Z_A}=E_{OA}Y_A=(E_{NA}-E_{NO})Y_A$$
$$I_B=(E_{NB}-E_{NO})Y_B \qquad (9)$$
$$I_C=(E_{NC}-E_{NO})Y_C$$

Since the sum of the currents is zero, addition of the right

Figure 3. Voltage diagram showing phase and line voltages of load and residual voltage E_{NO}



hand members of equations 9 yields a single expression involving but the one unknown E_{NO}. Thus

$$E_{NO}=\frac{E_{NA}Y_A+E_{NB}Y_B+E_{NC}Y_C}{Y_A+Y_B+Y_C} \qquad (10)$$
$$=15.13+j18.77 \text{ volts}$$

upon substitution for the known voltages and admittances.

Consequently, from equations 9, the actual voltages across the load elements are found. For example,

$$E_{OC}=(E_{NC}-E_{NO})$$
$$=(-50-j28.87)-(15.13+j18.77) \qquad (11)$$
$$=-65.13-j47.64 \text{ volts}$$

and

$$I_C=E_{OC}Y_C=-6.51-j4.76 \text{ amperes}$$

Another approach[4] by way of the residual voltage method is as follows. Were a zero impedance connection to exist between the two neutral points, N and O (they would now be the same point on a voltage diagram), the neutral current could be obtained readily as the vector sum of the three leg currents. If a voltage were inserted in the neutral lead so as to force an equal but opposite current through it, and thence through the three load impedances in parallel, the resultant neutral current would be zero, as is the case when O and N are not tied together. Now E_{NO} is that voltage and it can be calculated in such a manner. It is merely the product of the initial neutral current for an assumed neutral connection and the equivalent impedance of the three loads in parallel.

For the problem under discussion,

$$I_{ON}=-2.89-j5 \text{ amperes}$$

if N and O are connected. Hence

$$E_{NO}=I_{NO}Z_{\text{equiv}}=I_{NO}/(Y_A+Y_B+Y_C)$$
$$=(2.89+j5)/(0.2366-j0.0366)$$
$$=15.13+j18.77 \text{ volts}$$

This last method of solution can be handled very nicely by graphics if one desires.

It should be pointed out here that there is a fundamental similarity between methods (*b*) and (*c*). If N is chosen as the reference point in method (*b*), equations 7 and equations 9 are essentially the same, since, for example,

$$E_{OA}=E_{NA}-E_{NO}=E_{NA}-(a+jb)$$

Method (*d*). Extending the previous method, the voltages across the load elements can be expressed directly in terms of the known line voltages and the load admittances. Thus, substituting E_{NO} of equation 10 in equation 11, we have,

$$E_{OC}=\frac{E_{BC}Y_B-E_{CA}Y_A}{Y_A+Y_B+Y_C} \qquad (12)$$
$$=-65.1-j47.7 \text{ volts}$$

when the indicated calculations are fully carried out. Consequently,

$$I_C = E_{OC}Y_C = \frac{E_{BC}Y_BY_C - E_{CA}Y_AY_C}{Y_A+Y_B+Y_C} \qquad (13)$$
$$= -6.51-j4.77 \text{ amperes}$$

Methods (*c*) and (*d*) may be thought of as treatments by superposition in which the current distribution due to the system of voltages E_{NA}, etc., is added to that for the residual voltage E_{NO}. The algebraic analysis, however, sidesteps any requirement of actually calculating the two distributions of current.

Comparison of equations 5 and 13 show them to be the same, if substitution is made of reciprocal admittances for the impedances, or vice versa.

Method (*e*). While the algebra of the two previous analyses pointed to superposition, actual current components were not determined. One can solve the unbalanced wye, however, strictly by superposition. Take first the phase voltage E_{NA} of the supply, this voltage acting on the impedance Z_A in series with the parallel combination of Z_B and Z_C. The complete current distribution in the system is found for this arrangement. Next E_{NB} is applied to Z_B in series with the parallel combination of Z_A and Z_C, and a second current distribution found. Lastly, E_{NC} gives rise to its system of currents. Addition of the three separate current components in each leg of the load yields the resultant line currents.

Although this method is a possibility, it is not so straightforward as are the other schemes, and the great number of calculations with complex quantities makes it tedious. However, to show the application here, I_c is found by this method of analysis.

The impedance of the path to which E_{NA} is applied is

$$z_A = Z_A + (Z_BZ_C)/(Z_B+Z_C) = 13.66+j2.11 \text{ ohms}$$

Similarly, for E_{NB} and E_{NC}, respectively,

$$z_B = 10-j7.32$$

and

$$z_C = 16.83-j1.83$$

Due to E_{NA}, the current through Z_A is $(0.639+j4.13)$ amperes, with the component $-(1.51+j1.88)$ amperes through Z_C. Due to E_{NB}, the current component through Z_C is found similarly to be $-(2.24+j0.88)$, and by virtue of E_{NC} there exists $-(2.75+j2.01)$ amperes in Z_C. Conventions on direction of current flow through Z_C introduce the negative signs for the first two components. The sum of the three currents therefore is

$$I_C = -6.50-j4.77 \text{ amperes}$$

Method (*f*). A development of the method of symmetrical components is beyond the scope of this discussion, and it is hoped that the reader will refer to the subject in one of the standard textbooks for further information on it. Three of the many sources available are the books named in references 5, 7, and 9.

It is sufficient here to state that any three-phase voltage or current system, unbalanced and unsymmetrical, can be resolved into three component systems. The first (positive-sequence) system is balanced and of the same sequence as the initial system. The second (negative-sequence) system also is balanced but has the opposite phase sequence, while the third (zero-sequence) system is given by three equal vectors having the same phase position. Let these component systems be designated respectively by the subscripts 1, 2, and 0.

Remembering that the three vectors of a balanced system are 120 degrees apart, by introducing the unit operator a,

$$a = 120\text{-degree operator} = -0.5+j0.866$$
$$a^2 = -0.5-j0.866, \quad a^3 = 1+j0$$

any two of the three vectors can be written in terms of the third, which then might be called the reference vector for that voltage or current system. The operator a (Karapetoff calls it a "turning operator") is similar to the 90-degree operator j, and by means of it we can write I_1, a^2I_1, and aI_1 for the positive sequence currents in, say, lines A, B, and C, respectively. Likewise, the negative sequence currents are I_2, aI_2, and a^2I_2. The three zero sequence currents are all I_0.

For an unsymmetrical current system, therefore,

$$\begin{aligned} I_A &= I_1+I_2+I_0 \\ I_B &= a^2I_1+aI_2+I_0 \\ I_C &= aI_1+a^2I_2+I_0 \end{aligned} \qquad (14)$$

The problem lies in determining the magnitudes and positions of the reference components I_1, I_2, and I_0. Note that while the components in line A have been chosen above as the reference currents, they can just as well be assigned to either of the other lines. Furthermore, it is not necessary that the reference currents exist together in the same line. Figure 4 shows the voltage and current systems for the problem at hand in terms of the operator a. In this case, since we are interested first in I_C, let line C be chosen to

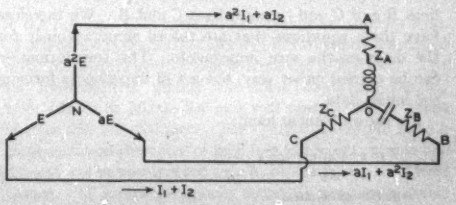


Figure 4. Supply voltages and current components for solution by method of symmetrical components

carry the reference currents, and E_{NC} be taken as the reference voltage E. Only positive and negative sequence currents can exist in the lines, because zero sequence currents cannot flow without a neutral lead. The supply voltages are balanced, hence in themselves they form only a positive sequence voltage system.

The voltage between B and C is $(E-aE)$, and equating this to its components for the two adjacent legs, we have

$$E-aE = (I_1+I_2)Z_C-(aI_1+a^2I_2)Z_B$$

Similarly, between A and C,

$$E-a^2E = (I_1+I_2)Z_C-(a^2I_1+aI_2)Z_A$$

Substituting complex quantity magnitudes for the voltage, the operator, and the impedances, the two equations just given become

$$-100=(5-j8.66)I_1+20I_2$$
$$-50-j86.6=(10+j10)I_1+(18.66-j5)I_2$$

from which

$$I_1=-4.27-j3.90$$
$$I_2=-2.24-j0.87$$

and

$$I_C=I_1+I_2=-6.51-j4.77 \text{ amperes}$$

Application of symmetrical components to this type of problem is basically the same scheme as method (*a*). $(E-aE)$ replaces E_{BC}, etc., for the voltages between terminals, and the line currents are given by two components. The circuit equations are the same in form, although only two are required here for determination of the unknowns I_1 and I_2. While the method of symmetrical components as applied here has no great advantage over other methods already described, its use may have considerable appeal for those who understand it.

Method (*g*). Lastly, the given wye set of impedances can be replaced by an equivalent set of impedances in delta and the current in any line found as the sum of the currents in the two adjacent legs of the delta. In this scheme of transformation, the impedances of the delta circuit between any two lines is made equal to the impedance of the wye circuit between the same lines. Thus, referring to figure 5, between lines *A* and *B*,

$$Z_Y=Z_A+Z_B=Z_\Delta=\frac{Z_{AB}(Z_{BC}+Z_{CA})}{Z_{AB}+Z_{BC}+Z_{CA}}$$

Similar equations are written for the impedances between lines *B* and *C* and between lines *C* and *A*. We therefore have three equations that are solved simultaneously for the delta or the wye impedances. The transformation can be carried either way, one set of impedances forming the initial data.

For the problem at hand,

$$Z_{AB}=\frac{Z_AZ_B+Z_BZ_C+Z_CZ_A}{Z_C}=\frac{\Sigma ZZ}{Z_C}$$
$$=22.32-j8.66 \text{ ohms}$$

when the substitutions are made and the indicated steps carried out. Similarly,

$$Z_{BC}=\frac{\Sigma ZZ}{Z_A}=14.99-j18.66$$

and

$$Z_{CA}=\frac{\Sigma ZZ}{Z_B}=18.66+j14.99$$

Now

$$I_C=\frac{E_{BC}}{Z_{BC}}-\frac{E_{CA}}{Z_{CA}}$$
$$=\frac{-100}{14.99-j18.66}-\frac{50+j86.6}{18.66+j14.99}$$
$$=-(2.62+j3.26)-(3.89+j1.51)$$
$$=-6.51-j4.77 \text{ amperes}$$

Again, this form of attack offers no advantage over earlier schemes. One difficulty, met immediately, is the great amount of complex-quantity algebra which may be introduced in calculating the equivalent impedances.

OTHER CIRCUIT QUANTITIES

In the several methods of calculation on the load system of figure 1, only the one current I_C was found. The same methods, however, apply exactly to the determination of the other two currents. Once the line currents are obtained, the phase voltages (if they are not known already through the particular method employed) become available immediately, and with them the phase angles between leg currents and voltages. The system power is simply the sum of the I^2R losses for the three legs, or can be found as the sum of two wattmeter readings in the conventional way.

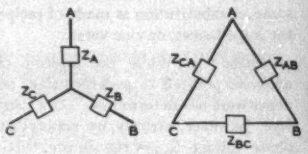


Figure 5. Notation on impedances for wye-delta transformation

To complete the story, the load currents and voltages are:

$I_A=0.64+j4.12$ amperes — $E_{OA}=-15.1+j39.0$ volts
$I_B=5.87+j0.64$ — $E_{OB}=34.9-j47.6$
$I_C=-6.51-j4.77$ — $E_{OC}=-65.1-j47.7$

GENERAL COMMENTS

The methods illustrated are equally adaptable to unbalanced loads taking power from an unbalanced voltage supply. No modifications whatever are necessary except in the case of symmetrical components, in which the supply voltage then is resolved into its component systems. For some of the other methods, depending upon the particular one in view, knowledge may be required on the position of the neutral of the supply, or, what is equivalent, on the phase voltages of the supply. It should be apparent that the balanced circuit, which is but a special case, is included in any discussion on the unbalanced system.

Reversed phase rotation will produce a second set of load currents and voltages for the phases, these new values in general differing from the ones calculated here. The problem may be approached by interchanging any two phase voltages and from them obtaining expressions for the new line voltages, or by interchanging directly any two line voltages. These steps are equivalent. Again, phase and line voltages can be left as they stand initially, the phase rotation reversed by considering actual reversal of the generator which produces these voltages. Clockwise angles now become positive, whence all the impedances

$$Z=R\mp jX$$

are changed to

$$Z=R\mp jX$$

In any case, the steps from this point on are identical with those shown in the methods described. These various treatments with reversed rotation yield among themselves the same magnitudes of voltages, currents, and phase angles, but one method may show an angular shift, forward or backward, of the complete vector diagram of all quantities with respect to the diagram for another method.

Specifically, interchanging E_{NB} and E_{NC}, for example, we have

$E_{NA} = 0 + j57.74$ volts
$E_{NB} = -50 - j28.87$
$E_{NC} = 50 - j28.87$

$E_{AB} = -50 - j86.6$ volts
$E_{BC} = 100 + j0$
$E_{CA} = -50 + j86.6$

whence the new line currents are

$I_A = 1.28 + j8.26$ amperes
$I_B = -3.26 - j7.39$
$I_C = 1.98 - j0.87$

While there are other extensions, of course, in the entire treatment on unbalanced systems, they are not included in the scope of this article. The aim has been to present general methods of attack on a very common problem. Of the several methods described, the last three may not be so satisfactory as are the others. They possess no advantages over the first four schemes, and are more indirect. Of the first four methods, personal appeal more often than not may determine which will be chosen. The quantity primarily desired—line current, leg voltage, or shift of the neutral from balanced loading—also may influence the selection of the method adopted. Again, the tools—such as the vector slide rule—used in calculating numerical results may make one scheme appear more suitable than others.

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The Colorado—Big Thompson Project

CULMINATING 50 years of effort on the part of the people of Colorado to secure additional irrigation water for northeastern Colorado, the Colorado Big Thompson project entered the construction stage in December 1938. A Bureau of Reclamation project, the general plan of the complete development from the standpoint of future operation, will extend from the vicinity of Kremmling on the western slope of the Continental Divide to Julesburg and the state line on the eastern slope.

The principal purpose of this project is to furnish annually an estimated 320,000 acre-feet of western-slope water for 615,000 acres of Colorado farm land on the eastern slope. This water will be delivered to existing eastern slope irrigation systems to complete the moisture requirements of the growing season. As a secondary purpose, the project will be capable of supplying annually 360,000,000 kilowatt-hours of firm hydroelectric energy and 332,000,000 kilowatt-hours of secondary energy. This energy will be available to markets in the vicinity after the deduction of sufficient energy to operate the project.

Five reservoirs, six power plants, two pumping plants, and a 13-mile tunnel comprise the major engineering units in the project. The reservoirs will range in capacity from 50,000 to 483,000 acre-feet and will be formed by a series of earth-fill dams ranging in height from 128 to 270 feet. The six hydroelectric plants will have capacities ranging from 16,000 to 50,000 kw and will operate under heads of some 250 to 1,200 feet. The 13-mile tunnel will have a cross-sectional diameter of 9.75 feet inside of concrete lining and will be constructed with a constant slope from west to east. Of sufficient capacity to satisfy the annual diversion requirements and augmented by sufficient storage facilities on the eastern slope, the small-size tunnel can provide a maximum amount of firm hydroelectric energy through continuous operation.

Two of the five reservoirs will be on the western slope. With the western-slope replacement storage thus provided by the project, all water diverted will be in excess of present and future requirements for lands on the western slope. Western-slope water for diversion to the eastern slope will be pumped from the upper of the two western-slope reservoirs to a storage lake at the western end of the 13-mile tunnel. Off-peak power from two of the six power plants will be used for the pumping operation.

The project also requires the construction of a series of canals, closed conduits, and syphons connecting the various units.

From an article of the same title by M. S. Bitner, associate engineer, Bureau of Reclamation, and published in the Reclamation Era, September 1940, pages 207–9.

Institute Activities

National • • • •

Radio Programs on Defense Work Sponsored by AIEE

Enlistment of the far-reaching resources of the electrical engineering profession in the Army, the Navy, and in defense production has been selected as the subject of a series of Monday night broadcasts sponsored by the AIEE over the "blue network" of the National Broadcasting Company. These 15-minute programs run from 7:45 to 8:00 p.m. (Eastern Standard Time). The first program originated in Philadelphia, January 27, 1941, the opening day of the AIEE winter convention. Subsequent broadcasts will be from NBC studios in New York. The broadcast series was arranged through the educational division of NBC.

Participating in the first program were Doctor R. W. Sorensen, president of the Institute; J. V. B. Duer, chief electrical engineer of the Pennsylvania Railroad; N. E. Funk, vice-president in charge of engineering, Philadelphia Electric Company, and Joseph W. Barker, dean of engineering, Columbia University. This broadcast was concerned with the part being taken by the electrical engineer in the nation's power and communication facilities and transportation systems.

The second program, February 3, describing the part played by the electrical engineer in the Army, is scheduled to include an interview with General J. O. Mauborgne, chief signal officer, United States Army. The third will tell how the resources of the electrical engineer have been utilized by the Navy. Succeeding broadcasts will relate to the participation of the electrical engineering profession in making America strong by steadily increasing its production, speeding up research, and expanding its technical facilities. The following have been scheduled to date:

January 27. Contributions of the Electrical Engineer to National Defense

February 3. The Electrical Engineer in the Army

February 10. The Electrical Engineer in the Navy

February 17. The Electrical Engineer in Defense Production

February 24. Mobilizing Electric Power for Defense

March 3. Electrical Research for Defense

Future AIEE Meetings

Great Lakes District Meeting
Fort Wayne, Ind., April 23–25, 1941

North Eastern District Meeting
Rochester, N. Y., April 30–May 2, 1941

Summer Convention
Toronto, Can., June 16–20, 1941

Pacific Coast Convention
Yellowstone National Park, August 27–29, 1941

Winter Convention Report to Appear in March Issue

As this issue goes to press the Institute's 1941 winter convention gets under way at Philadelphia, Pa. Early indications are that this first winter convention since 1924 to be held outside New York City is continuing the successful record of recent years. Registration for the first two days totaled 1,278, as compared with 1,178 for the first two days of the 1940 convention, 1,159 for 1939, and 1,027 for 1938. The March issue will contain the full report of the convention.

Personal • • •

C. W. Franklin (M'24) formerly assistant electrical engineer, Consolidated Edison Company of New York, Inc., New York, N. Y., has been made electrical engineer. Among other changes resulting from recent organizational shifts in Consolidated Edison, **J. E. Goodale** (A'21, F'34) formerly manager of the substation operation department, has been made assistant electrical engineer; **J. A. Brooks** (A'25, F'34) formerly distribution engineer, is now manager of substation operation, and **G. T. Minasian** (A'25, M'30) succeeds Mr. Brooks. **S. A. Warner** (A'27, M'30) has been made assistant distribution engineer, his former position of assistant outside plant engineer having been taken over by **J. E. McCormack** (A'27, M'37) formerly division engineer. **L. K. Murphy** (A'29) formerly manager of the construction contracts bureau, now heads the purchasing and stores department as purchasing agent; **Pincus Spiller** (A'38) former manager of the electrical equipment bureau, is now assistant purchasing agent; and **George Sutherland** (A'20, F'27) former assistant manager of the outside plant construction department, is now general stores manager. **J. F. Mulligan** (A'29, M'37) former superintendent, transmission division, is now general superintendent, installation and apparatus bureau (formerly apparatus maintenance division) of the electric distribution construction department (formerly distribution construction department). **A. R. Collard** (A'36) formerly superintendent of the consumers and emergency division, Manhattan and Bronx, is now assistant general superintendent of the underground bureau. **Ferdinand Zogbaum** (A'09, M'15) formerly co-ordinating engineer, is now assistant to the manager of the contract inspection department (formerly contract control and inspection department). **J. J. Ryan** (A'37) formerly assistant general superintendent of the distribution operation department, is now general superintendent of the combined gas and electric meter divisions, which have been added to the department. **R. F. Brower** (M'34) former assistant system engineer, system engineering department, has been made system engineer. **L. E. Frost** (A'22, M'30) formerly assistant to vice-president in charge of research development and planning, is now research and development engineer, heading the research and development department.

H. M. Hobart (A'94, F'12) has retired as consulting engineer, General Electric Company, Schenectady, N. Y., and will engage in private consulting practice. He was born in Boston, Mass., November 29, 1868, and received the degree of bachelor of science in electrical engineering from Massachusetts Institute of Technology in 1889. He entered the employ of the Thomson-Houston Electric Company, Lynn, Mass., in 1889, was transferred to General Electric Company at Schenectady during 1894–95, and returned to Lynn the following year. From 1896 to 1900 he was with the British Thomson-Houston Company, London, England, and from 1900 to 1903 with the Union Electricitats Gesellschaft, Berlin, Germany. During the next eight years he carried on private consulting practice in London, returning to General Electric Company in 1911 as consulting engineer, in which position he continued until his recent retirement. He received the Samuel Wylie Miller Medal of the American Welding Society in 1936. He is author and co-author of a number of books and articles, and holder of some 30 patents, some in collaboration. He has served the Institute as a manager (1922–26), vice-president (1926-28), on various committees and as representative on other organizations, notably the United States National Committee of the International Electrotechnical Commission (1914–32). He has been particularly active in standards work, and is also a member of the American Welding Society, American Society of Mechanical Engineers, American Association for the Advancement of Science, and of the British Institutions of Civil Engineers, Electrical Engineers, and Mechanical Engineers.

H. V. Putman (A'23, M'32) formerly manager of engineering, transformer works, Westinghouse Electric and Manufacturing Company, Sharon, Pa., has been appointed manager of the transformer division. A native (1899) of Barker, N. Y., he received the degrees of bachelor of science in electrical engineering, 1920, master of science, 1921, and doctor of philosophy, 1923, from

Union College. After two years with the Ideal Electric and Manufacturing Company, Mansfield, Ohio, he joined the Westinghouse company in 1925, becoming section engineer in 1928, and manager of engineering in 1931. **J. K. Hodnette** (A'25, M'30) former transformer development engineer, has been appointed manager of engineering, transformer division, Sharon. He has been with the Westinghouse company since 1923, and a transformer engineer since 1925. **H. B. West** (A'24) former division engineer, has been appointed manager of manufacturing in the transformer division at Sharon. He joined the Westinghouse company in 1919, and since 1935 has had charge of instrument and regulator engineering.

H. V. Bozell (A'08, F'23) formerly vice-president, General Telephone Corporation, New York, N. Y., has been elected president of that company. Born at Beloit, Kans., May 31, 1886, he received the degrees of bachelor of science in electrical engineering, 1908, and electrical engineer, 1915, from the University of Kansas. From 1908 to 1916 he was successively assistant professor, associate professor, and professor of electrical engineering, University of Oklahoma, Norman, and from 1916 to 1921 assistant professor of electrical engineering, Yale University, New Haven, Conn. In 1920 he also became co-editor of *Electric Railway Journal*, published by the McGraw-Hill Publishing Company, New York, N. Y., continuing with the company as first editor of *Bus Transportation*, and from 1922 to 1925 as co-editor of *Electrical World*. He went with Bonbright and Company, investment bankers, in 1925, and in 1932 became vice-president of Associated Telephone Utilities Company, predecessor of General Telephone corporation.

P. O. Langguth (A'28) formerly design engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed assistant manager, circuit breaker and protective devices engineering, switchgear division. He has been with the company since 1924 and formerly was in charge of small oil circuit-breaker engineering. **H. J. Lingal** (A'33) formerly section engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been given special assignments in connection with large oil circuit breakers, switchgear division. **A. J. A. Peterson** (A'16, M'30) former manager of circuit breaker engineering, switchgear division, has been made project section engineer, switchboard engineering, switchgear division. Other changes in the switchgear division include the appointment of the following as section engineers, circuit breaker and protective devices engineering: **R. C. Dickinson** (A'37), **G. G. Grissinger** (M'38), **A. W. Hill** (A'38), **W. M. Leeds** (A'32, M'38), **H. L. Rawlins** (A'30), **H. M. Wilcox** (M'27).

C. H. Taylor (A'07, M'24) has retired as vice-president in charge of engineering, RCA Communications, Inc., New York, N. Y. Born August 22, 1875, at Hayes, Middlesex, England, he received his technical education at Heriot Watt College, Edinburgh, Scotland. He was employed by New and Mayne, Ltd., B. F. Sturtevant Company, Wireless Telegraph and Signal Company, and Evershed and Vignoles, Ltd., in England, before coming to the United States in 1902, when he joined the Marconi Wireless Telegraph Company of America. He engaged in the construction and operation of radio stations in various parts of the United States and in Brazil, and supervised construction of the transoceanic stations built along the Atlantic and Pacific coasts and in Hawaii. When the Radio Corporation of America was formed in 1920 he became its acting chief engineer, and in 1924 was made chief communications engineer. He was later appointed vice-president of RCA Communications, Inc.

H. H. Beverage (A'23, M'34) chief research engineer, RCA Communications, Inc., New York, N. Y., has been made vice-president in charge of research and development. Born at North Haven, Maine, October 14, 1893, he received the degree of bachelor of science in electrical engineering in 1915 from the University of Maine which awarded him the honorary degree of doctor of engineering in 1938. He went with General Electric Company, Schenectady, N. Y., in 1915, and after a year on general testing became radio laboratory assistant. In 1920 he was placed in charge of radio research on communication equipment for Radio Corporation of America. He was transferred to RCA Communications, Inc., in 1929, as chief communications engineer, and since 1932 has been chief research engineer in charge of the research staff. In 1923 he was awarded the Morris Liebman Memorial Prize of the Institute of Radio Engineers. He is a past president of that society.

W. C. Smith (A'07, F'40) formerly engineer, San Francisco, Calif., office, General Electric Company, has been made district engineer, Pacific district. He entered the General Electric test course in 1905, and was transferred to transformer engineering in 1907. In 1920 he went to San Francisco as transformer specialist, and in 1932 became engineer of that office. **O. A. Gustafson** (A'25) formerly central station engineer, Los Angeles, Calif., becomes district central station engineer. He has been with General Electric since 1923, first at Schenectady, and since 1928 at Los Angeles. **R. G. Brosemer** (A'21, M'37) formerly assistant engineer, San Francisco office, has been made district industrial engineer. He joined the test course at Schenectady in 1925, was transferred to San Francisco in 1929, and has been assistant engineer since 1937.

C. F. Terrell (A'10, M'18) formerly operating manager of the Gulf States Utilities Company, Beaumont, Tex., has been appointed operating manager of Puget Sound Power and Light Company, Seattle, Wash., with duties including management of the central station division, and supervision of the system's generation, transmission, and distribution. First employed in 1903 by the Seattle Electric Company, one of the predecessors of Puget Sound Power and Light, he was made superintendent of light and power for the latter's northwest division, Bellingham, Wash., in 1922. In 1924 he became superintendent of light and power for the El Paso (Tex.) Electric Company, and was later general superintendent of the Tampa (Fla.) Electric Company, before going with Gulf States Utilities in 1929.

Fred Elwell (A'27) has retired as superintendent of hydroelectric power plants, British Columbia Electric Railway Company, Vancouver, B. C., Canada. Born February 14, 1874, at Horsham, Sussex, England, he was employed an apprentice in 1892 by Frank Suter and Company, electrical engineers, London, later becoming superintendent of construction. Coming to Canada in 1898, he became assistant superintendent and later superintendent of the Bonnington Falls, B. C., power plant of the West Kootenay Power and Light Company. He was employed by British Columbia Electric Railway Company in 1911 as superintendent of the powerhouse at Lake Buntzen, and was made superintendent of power plants in 1925.

J. O. Johnson (A'36) formerly assistant material engineer, United States Navy, Brooklyn, N. Y., has been appointed chief engineer of Industrial Manufacturers, Inc., Elizabeth, N. J. Born June 20, 1909, at Middlesex, Vermont, he received the degree of electrical engineer at Rensselaer Polytechnic Institute in 1931. He was employed by Sears, Roebuck and Company, Chicago, Ill., from 1931 to 1933, first on testing, and later as research and design engineer in the merchandise development division. He became junior material engineer in the electrical section of the material laboratory of the United States Navy Yard, Brooklyn, in 1934, and later assistant material engineer.

J. W. Barker (M'26, F'30) dean of engineering, Columbia University, New York, N. Y., has been elected a member of the executive committee of the council of American Association for the Advancement of Science, for a four-year term. Dean Barker has been active in Institute affairs for many years. He is current chairman of the AIEE technical program committee and committee on award of Institute prizes, and is a member of several other committees; he was chairman of the committee on education 1937–39. He is also a member of several other technical societies, and has been active in the division of engineering and research of National Research Council.

N. H. Callard (A'16) formerly sales counselor, Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa., has been appointed manager of distribution apparatus, agency sales department. He has been with the company since joining the apprentice course in 1912, except for Army service during the World War, and has served as salesman for the Salt Lake City, Utah, office, on syndicate operations in New York, N. Y., and from 1928 to 1939 as district central station manager on the

Pacific Coast. He recently has been engaged on staff assignments in the general sales department at Pittsburgh.

T. A. Abbott (A'26, M'31) formerly sales engineer, General Electric Company, Schenectady, N. Y., has been appointed manager of sales, meter division. He was a member of the General Electric test course 1925–26, and after five years as instructor in electrical engineering at Yale University, New Haven, Conn., he returned to the company in 1931 to take charge of meter and instrument courses in the meter engineering department at Lynn, Mass. He became superintendent of the meter department in 1937 and in 1940 was transferred to meter sales at Schenectady.

J. H. Edwards (M'20) associate editor, *Coal Age*, McGraw-Hill Publishing Company, Inc., has been appointed electrical editor of *Engineering and Mining Journal*, also a McGraw-Hill publication. He continues in his former capacity with *Coal Age*, with headquarters for both at Huntington, W. Va. He has been with *Coal Age* since 1924, having previously been engaged in electrical work for the Chicago, Rock Island, and Pacific Railway Company, Silvis, Ill., 1913–18, and the Elkhorn Piney Coal Mining Company, Huntington, 1918–24.

W. R. MacDonald, Jr. (A'33) editorial assistant, American Institute of Electrical Engineers, New York, N. Y., has been ordered to active duty as first lieutenant in the Signal Corps, United States Army, with headquarters at Washington, D. C. He has held a commission in the Signal Corps Reserve since 1932. A native (1910) of New York, he received the degree of electrical engineer from Cornell University in 1932. He has been employed in the editorial department of the Institute since 1934.

Donald Fisher (A'35) formerly division plant superintendent, Division 1, New York, N. Y., long lines department, American Telephone and Telegraph Company, has been appointed engineer of outside plant. **G. H. Quermann** (A'22) formerly division plant superintendent, Division 5, St. Louis, Mo., has been appointed general plant superintendent, southern. **J. W. Creasy** (A'20, M'29), engineer of outside plant, New York, N. Y., becomes division plant superintendent, St. Louis.

C. V. Aggers (A'39) former liaison engineer, engineering laboratories and standards department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been made manager of manufacturing and engineering, Westinghouse X-Ray Company, Long Island City, N. Y. A native (1905) of Franklin, Pa., he has been with the Westinghouse company since 1925, in various departments, and has been liaison engineer since 1937.

C. C. Shutt (A'28) formerly manager of engineering, small motors division, Westinghouse Electric and Manufacturing Company, Lima, Ohio, has been made manager of the small motors division. He was born in 1902 and received the degree of bachelor of science in electrical engineering from Iowa State College in 1926. He entered the Westinghouse graduate course immediately after graduation, and has been with the company ever since.

D. P. Fullerton, Jr. (A'29) who was in charge of the Bell System exhibit at the 1940 New York World's Fair, has been appointed engineer of buildings and equipment, Long Island area, New York Telephone Company, New York, N. Y.

National Defense Appointments

The following members of the Institute are among those who have received recently appointments to the United States Army, Navy, or Air Corps, in most cases in connection with the national defense program. **G. F. Tinkler** (A'36) junior valuation engineer, State of California, Sacramento, is now lieutenant, United States Army, Fort McQuaid, Watsonville, Calif. **G. D. Burton** (A'39) meter tester Idaho Power Company, Pocatello Falls, is now junior electrical engineer, Navy Bureau of Ordnance, Washington, D. C. **B. F. Meador** (A'29, M'35) electrical engineer, Black and Veatch, Kansas City, Mo., is now major in the field artillery reserve, United States Army, St. Louis, Mo. **J. F. Sodaro** (A'39) partner, Sodaro Manufacturing Company, Chicago, Ill., is now an aviation cadet, United States Naval Air Station, Pensacola, Fla. **J. E. Breth** (A'38) assistant electrical engineer, Consolidation Coal Company, Inc., Fairmont, W. Va., is now major, Office of the Quartermaster General, War Department, Washington, D. C. **H. C. Brown** (A'39) Joseph T. Ryerson and Son, St. Louis, Mo., and **R. A. Greulich** (A'37) transmission man, Pacific Telephone and Telegraph Company, Reno, Nev., are now at Fort Winfield Scott, San Francisco, Calif. **Chandler Stewart, Jr.** (A'40) is now employed as junior radio engineer, Navy Department, Vallejo, Calif. **F. P. Quigley** (M'33) power division, Public Works Administration, Washington, D. C., is now lieutenant commander, United States Naval Reserve, Bureau of Ships, Navy Department, Washington. **J. F. Marotta** (A'40) who enlisted in the United States Army Signal Corps in December 1939, is now corporal, 311th Signal Aviation Company, Hamilton Field, Calif. **W. K. St. Clair** (A'22, M'28) equipment engineering department, Bell Telephone Laboratories, New York, N. Y., is now at the United States Army Corps Area Signal Office, Governors Island, N. Y. **N. J. Bukey** (A'31, M'38) supervisor, cable construction department, Cincinnati (Ohio) Gas and Electric Company, is now captain, Coast Artillery, Fort Monroe, Va.

Obituary • • •

Lewis Buckley Stillwell (A'02, M'02, F'12) consulting engineer, Princeton, N. J., died January 19, 1941, at Baltimore, Md. He was a past president of the Institute (1909–10), recipient of the Lamme and Edison medals and of various other awards, and one of the outstanding pioneers in high-voltage transmission. A complete biographical sketch will appear in the March issue.

Leo Alonzo Phillips (A'94, M'11, F'13) retired consulting engineer, New Orleans, La., died December 9, 1940, at Montgomery, Ala. He was born September 8, 1872, at New Orleans, La., and educated there. After a year as apprentice with the Louisiana Electric Light and Power Company, New Orleans, he entered the Edison Machine Works, Schenectady, N. Y. (a predecessor of the General Electric Company), as a student in 1889. In 1892 he went with the Edison Electric Illuminating Company of New York, N. Y., and in 1893 was employed by the Westinghouse Electric and Manufacturing Company as a student at the Newark, N. J., shops, later being transferred to East Pittsburgh, Pa. From 1897 to 1900 he was superintendent of the Flushing, N. Y., plant of the New York and Queens Light and Power Company. During 1900 he was in charge of the installation and operation of the substation at the Paris Exposition, for the French Westinghouse Company, Paris. He was employed successively by the Trade Dollar Consolidated Mining Company of Pittsburgh, Pa., at its power plant at Snake River, Idaho; as electrical engineer for the consulting firm of Sanderson and Porter, New York, N. Y.; and in the Pittsburgh sales office of the Westinghouse company before becoming sales engineer for the Allis-Chalmers Manufacturing Company, at Pittsburgh in 1908. In 1910 he was transferred to Milwaukee, Wis., as assistant chief engineer, later becoming special engineer. He went into the steam and electrical equipment business in New York, N. Y., about 1916. Some ten years later he became consulting engineer for the Pittsburgh Vetagrande Mining Company, Zacatecas, Mexico, a year later becoming vice-president and chief engineer of the Federal Water Service Corporation, New York, N. Y., and later chief engineer for Charles A. Smith and Company, Engineers, New York. He engaged in consulting engineering practice in Brooklyn, N. Y., for about five years before his recent retirement.

Lewis Degen (A'95, M'13) retired consulting electrical signal engineer, Burlingame, Calif., died December 22, 1940. He was born November 20, 1862, at Ottawa, Ill., and educated there. He began his career in 1888 as a partner in the firm of Armstrong and Degen, constructing electrical engineers, Englewood, Ill. The following year he was responsible for constructing the lighting systems for the towns of Marseilles and Ottawa, Ill., and later he became superintendent of the Illinois Electric Light and Power Company. Turning to electric street railway construction, he worked as erecting and superintending engineer in Joliet and Ottawa, Ill., San Jose, Calif., and Denver, Colo. In 1892 he joined the Thomson Houston International Electric Company and was sent to Rio de Janeiro, Brazil, where he installed the electric street railway system. He became constructing electrical engineer for the Sao Paulo, Brazil, Tramway, Light, and Power Company about ten years later. He remained in Brazil as a construction engineer until 1913, when he returned to the United States, settling at Long Beach, Calif. Later he went to Pasadena, Calif., where he installed the city's fire alarm system. In

1920 he became electrical engineer for the Pacific Fire Extinguisher Company, San Francisco, Calif., and in 1923 consulting electrical signal engineer for the City of Los Angeles, Calif. He later extended his consulting practice to other cities and was active in it until 1940.

Ernest Ingalls Dyer (A'99) consulting engineer, Piedmont, Calif., died February 4, 1939, according to information just received. He was born at Alvarado, Calif., September 4, 1872, and was graduated from the College of Mechanics of the University of California in 1894, afterward taking a year's graduate work in electrical engineering. He was employed by the San Joaquin (Calif.) Electric Company for a short time, before being employed in 1897 as engineer and manager of the engineering department of the American Trading Company, at Yokohama, Japan, and Port Arthur, Manchuria. From 1904 to 1909 he was manager in Seattle, Wash., for Charles G. Moore and Company, Engineers, and the Babcock and Wilcox Company. From 1909 to 1925 he was associated with the Union Oil Company of California, first as engineer in the manufacturing department, becoming engineer in chief and manager of that department, and later technical director of the company and a member of the board of directors and the executive committee. He was also a director and technical engineer for the Union Oil Company of Canada, 1920–24. Since 1924 he had been president of the Dyer Estate Company. He had retired from active engineering practice. He was the author of several inventions.

Fulgencio Archila (A'29) assistant engineer, Interborough Rapid Transit Company, New York, N. Y., died December 3, 1940. He was born October 13, 1891, at Sogamoso, Colombia, and was graduated in 1912 from the Escuelade Mecanica, Bogota, Colombia, and received the degree of electrical engineer in 1916 from the Instituto Tecnico Superiore, Milan, Italy. From 1916 to 1919 he was an assistant electrical engineer with Pirelli and Company, Milan. For the next four years he was engineer of electrical and mechanical construction, General Engineering Works, Bogota, and at the same time professor of electricity at the Universidad Colombiana de Ingenieros, Bogota. He came to the United States in 1923 and the following year was employed as electrical draftsman in the office of the chief engineer, Interborough Rapid Transit Company, later becoming engineer in the chief engineer's office, and recently assistant engineer of the company.

Adolph H. Rapport (A'30, M'40) instructor in electrical engineering, College of the City of New York, New York, N. Y., died December 17, 1940. He was born at New York February 8, 1908, and received the degrees of bachelor of science, 1927, and electrical engineer, 1928, from the College of the City of New York, and that of master of arts from Columbia University in 1938. He was employed by the New York Edison Company 1928–35, first for a training period in the distribution department, then as safety inspector, and from 1931 as junior engineer in the test bureau. Beginning in 1930 he was an instructor in electrical engineering at the evening sessions of the College of the City of New York, and since 1935 had been a full-time instructor in the day courses. He also had taught evening courses for the New York Edison and Consolidated Gas companies.

Henry M. Bostwick (A'21) director of lamp sales, Canadian Westinghouse Company, Ltd., Hamilton, Ont., Canada, died November 25, 1940. He was born at Ithaca, N. Y., December 6, 1877, and received the degree of mechanical engineer from Cornell University in 1901. He was employed by the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa., in the same year, and in 1903 was transferred to the East Pittsburgh office of Canadian Westinghouse. He was sent to Hamilton in 1906, becoming assistant manager of sales in 1909, and manager of sales in 1919. He held the latter position until 1939, when he became director of lamp sales.

Richard Oscar Nixon (A'22) superintendent of power, Philadelphia Rapid Transit Company, Philadelphia, Pa., died December 25, 1940. Born July 17, 1883, at Philadelphia, he received a certificate in electrical engineering from Drexel Institute in 1913, and continued graduate study at that institution afterward. From 1902 to 1904 he was a switchboard operator for the Philadelphia Electric Company. He went with the Philadelphia Rapid Transit Company in the same capacity in 1904, becoming system operator in 1913, engineering assistant in 1918, and superintendent of power about five years later.

Reginald Morley Prowse (A'39) assistant electrical engineer, Tata Iron and Steel Company, Ltd., Jamshedpur, India, died February 11, 1940. He was born December 24, 1905, at Torquay, England, and received the diploma of Faraday House in 1929. From 1930 to 1934 he was special representative in India for Westinghouse Electric International Company, and from 1935 to 1938 manager for India of Westinghouse Electric Company of India, Ltd. He had been with the Tata Iron and Steel Company since 1938. He was also a member of the Institution of Electrical Engineers of Great Britain.

Membership

Recommended for Transfer

The board of examiners, at its meeting on January 23, 1941, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Member

Chanon, H. J., electrical engineer, General Electric Company, Cleveland, Ohio.

Dean, S. M., chief assistant superintendent of electrical system, The Detroit Edison Company, Detroit, Mich.

Gruenburg, O. S., inspector of electrical engineering materials, U. S. Navy Department, Camden, N. J.

Hayward, C. D., relay development engineer, General Electric Company, Philadelphia, Pa.

Hoadley, H. E., chief distribution engineer, The Empire District Electric Company, Joplin, Mo.

McIlvaine, W. D., assistant engineer, Minneapolis-St. Paul Sanitary District, St. Paul, Minn.

Merriman, J. H., maintenance engineer, Northern States Power Company, Minneapolis, Minn.

Patterson, L. R., planning engineer, Public Service Company of Colorado, Denver, Colo.

Russell, J. B., assistant professor of electrical engineering, Columbia University, New York, N. Y.

Schuck, O. H., electrical engineer, C. G. Conn, Ltd., Elkhart, Ind.

Schultz, S. E., chief engineer, Bonneville Power Administration, Portland, Ore.

Thorson, W. R., general manager, Municipal Water and Light Plants, Muscatine, Iowa.

Wheeler, R. C. H., associate professor of electrical engineering, Postgraduate School, United States Naval Academy, Annapolis, Md.

Wilcox, S. C., electrical engineer, County Engineers Office—Cayahoga, Cleveland, Ohio.

Yagodkin, V. K., electrical engineer, Tennessee Valley Authority, Knoxville, Tenn.

15 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before February 28, 1941, or April 30, 1941 if the applicant resides outside of the United States or Canada.

United States and Canada

1. NORTH EASTERN

Andrias, J., Stone and Webster Engineering Corporation, Boston, Mass.

Borst, D. W., General Electric Company, Schenectady, N. Y.

Bowman, J. Y., General Electric Company, Schenectady, N. Y.

Bush, J. E., General Electric Company, Pittsfield, Mass.

Chin, P., General Electric Company, Schenectady, N. Y.

Deines, E. W., Jr., Narragansett Electric Company, Providence, R. I.

Dykstra, L. J., Victor Insulators, Incorporated, Victor, N. Y.

England, W. H., General Electric Company, West Lynn, Mass.

Frost, G. E., General Electric Company, Schenectady, N. Y.

Gara, W. B., United States Army Engineers, Fort Devens, Mass.

Graham, R. C., General Cable Corporation, Rome, N. Y.

Hart, J. L., General Electric Company, Schenectady, N. Y.

Hayes, T. B., Jackson and Moreland, Boston, Mass.

Lawry, C. C., Jr., General Electric Company, Schenectady, N. Y.

Lederer, E. H., General Electric Company, Schenectady, N. Y.

Lloyd, S. C., Jr., Remington Arms Company, Bridgeport, Conn.

McDorman, J. A., Jr., Allis-Chalmers Manufacturing Company, Boston, Mass.

Meyers, N. H., General Electric Company, Schenectady, N. Y.

Price, J. C., General Electric Company, Schenectady, N. Y.

Putnam, G. R., Chase Brass and Copper Company, Incorporated, Waterbury, Conn.

Rosenthal, E. M., Curtiss-Wright Corporation, Buffalo, N. Y.

Shepard, B. R., General Electric Company, Lynn, Mass.

Stowell, C. F., Corps of Engineers, United States Army, South Schenectady, N. Y.

Thiessen, A. E. (Member), General Radio Company, Cambridge, Mass.

West, E. S., Hygrade Sylvania Corporation, Salem, Massachusetts.

Wolfner, W. F., II., Photoswitch Incorporated, Cambridge, Mass.

2. MIDDLE EASTERN

Albright, W. D., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Bartlett, F., General Electric Company, West Philadelphia, Pa.

Berkley, L. H., Federal Power Commission, Washington, D. C.

Beyer, F. W., Autocall Company, Shelby, Ohio.

Biester, W. H., Jr., Electro Construction Company, Philadelphia, Pa.

Bleasey, J. C., General Motors Corporation, West Trenton, N. J.

Bradley, R., VI., Consolidated Gas, Electric Light and Power Company, Baltimore, Md.

Christy, H. A. (Member), National Youth Administration, Philadelphia, Pa.
Collis, H. O., Owens-Corning Fiberglas Corporation, Newark, Ohio.
Colman, C. W., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Crockett, E. G., 412 Morris Building, Philadelphia, Pa.
Dorn, W. C., Bra Bon Electric Company, Philadelphia, Pa.
Dralle, H. E., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Dunlap, H. B., Cincinnati Gas and Electric Company, Cincinnati, Ohio.
Edkins, E. V. (Member), Atlantic Refining Company, Philadelphia, Pa.
Elliott, C. L., Bureau of Aeronautics, Navy Department, Washington, D. C.
Elvove, E., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Fields, C. V., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Fisher, R. E., Consolidated Gas, Electric Light and Power Company, Baltimore, Md.
Praakenfield, A. W. (Member), E. I. du Pont de Nemours Company, Incorporated, Wilmington, Delaware.
Frasee, F. W., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Getaz, J. F., Ingersoll-Rand Company, Phillipsburg, N. J.
Haberland, E. R., United States Navy Yard, Washington, D. C.
Hazen, D. P., Jr., Western Union Telegraph Company, Cincinnati, Ohio.
Herr, D. L., United States Navy, Washington, D. C.
Hines, C. M., Westinghouse Airbrake Company, Wilming, Del.
Hoebel, H. F., The Toledo Edison Company, Toledo, Ohio.
Hudson, B. T., Carnegie-Illinois Steel Corp., Pittsburgh, Pa.
Hulse, E. H., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Kendall, P. R., Kendall Radio Company, Cleveland, Ohio.
Klar, R. L., Jr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Kovski, J. J., Aircraft Radio Laboratory, Wright Field, Dayton, Ohio.
Kozak, T. J., Toledo Edison Company, Toledo, Ohio.
Marras, A. W., The Babcock and Wilcox Company, Akron, Ohio.
Miller, R. L., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Moe, W. J., Rural Electrification Administration, Washington, D. C.
Muckley, M., Federal Machine and Welder Company, Warren, Ohio.
Nally, J. W., Robbins and Myers, Incorporated, Springfield, Ohio.
Nelson, R. N. (Member), Ohio Public Service Company, Ashland, Ohio.
Ogle, F. M., Trumbull Electric Manufacturing Company, Philadelphia, Pa.
Packard, C. C., Struthers Dunn, Incorporated, Philadelphia, Pa.
Paulson, A. W., New York Shipbuilding Corporation, Camden, N. J.
Penkow, J. B., Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa.
Pruitt, G. M., Jr., New York Shipbuilding Corporation, Camden, N. J.
Roberts, G. B., Philadelphia Electric Company, Philadelphia, Pa.
Ruhl, F. L., United States Navy Yard, Philadelphia, Pa.
Sherman, W. A., Duquesne Light Company, Pittsburgh, Pa.
Smitheman, E. W., 3rd, United States Navy Yard, Philadelphia, Pa.
Snyder, A. B., Jr., Appalachian Electric Power Company, Charleston, W. Va.
Sprowl, P. R., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Steelman, A. T., Jr., Bell Telephone Company of Pennsylvania, Philadelphia, Pa.
Thompson, C. E., Thompson Company, Philadelphia, Pa.
Viehahn, W. W., Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa.
Wagner, R. B., Chesapeake and Potomac Telephone Company, Washington, D. C.
Wright, L. L., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

3. New York City

Bates, A. A., New York and Queens Electric Light and Power Company, Flushing, N. Y.
Bowen, J. J., General Electric Company, New York, N. Y.
Bower, J., Consolidated Edison Company, New York, N. Y.
Bremer, F. V., WAAT Bremer Broadcasting Corporation, Jersey City, N. J.
Bull, R. H., Long Island Lighting Company, Glenwood Landing, N. Y.
Carty, J. P., Western Union Telegraph Company, New York, N. Y.
Dench, E. B., Interchemical Corporation, New York, N. Y.
Dubbs, W. P., Westinghouse Electric and Manufacturing Company, New York, N. Y.
Durfee, G. I., Westinghouse Electric and Manufacturing Company, New York, N. Y.
Evans, L. S., Consolidated Edison Company of New York, Incorporated, New York, N. Y.
Floyd, J. R., Westinghouse Electric and Manufacturing Company, Newark, N. J.
Fragola, C. F., Sperry Gyroscope Company, Garden City, L. I., N. Y.
Galbraith, S. L., Western Electric Company, Kearny, N. J.
Hatch, B. G., General Electric Company, New York, N. Y.
Hodges, H. L., Jr. (Member), New York and Queens Electric Light and Power Company, Flushing, N. Y.
Ibata, R. M., United States Signal Corps, Brooklyn, N. Y.
Joecks, A. K., Consolidated Edison Company of New York, Incorporated, New York City, N. Y.
King, H. T., Bell Telephone Laboratories, Incorporated, New York, N. Y.
Krueger, A. M., Ward Leonard Electric Company, Mt. Vernon, N. Y.
Lane, H. A., New York and Queens Electric Light and Power Company, Flushing, N. Y.
LeClair, W. R., Standard Coated Products Corporation, Buchanan, N. Y.
Lee, L. Y., Aircraft Radio Corporation, Boonton, N. J.
Mallinckrodt, C. O., Bell Telephone Laboratories, Incorporated, New York, N. Y.
Milton, L., Solar Manufacturing Corporation, Bayonne, N. J.
Nagy, A. W., Columbia University, New York, N. Y.
Nissley, R. R., Westinghouse Electric and Manufacturing Company, New York, N. Y.
Patterson, H. R., War Department, New York Signal Corps, Brooklyn, N. Y.
Rae, G. G., Holophane Company, Incorporated, New York, N. Y.
Rappaport, G., 92 Cook Street, Brooklyn, N. Y.
Reboul, H. (Member), Consolidated Edison Company of New York, Incorporated, New York, N. Y.
Rheaume, R. H., Western Electric Company, Incorporated, Kearny, N. J.
Roehm, F. J., War Department, New York Signal Corps, Brooklyn, New York.
Schimpf, L. G., Bell Telephone Laboratories, Incorporated, New York, N. Y.
Schramm, C. W. (Member), Bell Telephone Laboratories, Incorporated, New York, N. Y.
Sherman, H., War Department, New York Signal Corps., Brooklyn, N. Y.
Suski, H. M., Western Electric Company, Kearny, N. J.
Wessely, G., Consolidated Edison Company of New York, Incorporated, New York, N. Y.
Wilcox, J. L., Western Union Telegraph Company, New York, N. Y.
Williams, H. B. (Member), Columbia University, New York, N. Y.
Wright, R. R., New York University, New York, N. Y.

4. Southern

Beatty, P. B., Western Union Telegraph Company, Charlotte, N. Car.
Harder, R. N., Aluminum Company of America, Alcoa, Tenn.
Harrison, A. E., United States Army, Fort Jackson, S. Car.
Hollandsworth, F. M., Memphis Light, Gas and Water Division, Memphis, Tennessee.
Jones, L. F., The Little Ocmulgee Electric Membership Corporation, Alamo, Ga.
Klein, National Advisory Council for Aeronautics, Langley Field, Virginia.
Lawson, H. L., Memphis Light, Gas and Water Division, Memphis, Tenn.
McGillivray, A., Tennessee Valley Authority, Wilson Dam, Ala.
Obrecht, R. G., Tennessee Valley Authority, Chattanooga, Tenn.
Ostaff, W. A., Trumbull Electric Manufacturing Company, Ludlow, Ky.
Stegner, A. L. (Member), Ray W. Chanaberry, Incorporated, Louisville, Ky.

5. Great Lakes

Badgett, E. D., Granite City Steel Company, Granite City, Ill.
Basic, R., Russell Electric Company, Chicago, Ill.
Brokaw, R. T., Jr., Barnes Drill Company, Rockford, Ill.
Carlson, McK. S. (Member), Commonwealth Edison Company, Chicago, Ill.
DeBoer, H. H., Michigan Bell Telephone Company, Detroit, Mich.
Findley, R. L. (Member), Westinghouse Electric and Manufacturing Company, Detroit, Michigan.
Gable, J. G., Cutler-Hammer, Incorporated, Milwaukee, Wisconsin.
Gollin, N. W., 1218 Washtenaw, Ann Arbor, Mich.
Gossman, L. E., General Electric Company, Fort Wayne, Ind.
Gray, A. S., Insulation Manufacturers Corporation, Chicago, Ill.
Hird, F. S., Northwestern Bell Telephone Company, Davenport, Iowa.
Jones, D. L., Automatic Electric Company, Chicago, Ill.
Kieb, N. J. (Member), Albert Kahn Incorporated, Detroit, Michigan.
Latta, H. A., Howell Electric Motors Company, Battle Creek, Michigan.
Little, G. W., Chrysler Corporation, Detroit, Michigan.
Lueders, B. C., Prairie Du Sac, Wisconsin.
MacKinnon, R. H., Public Service Company of Northern Illinois, Evanston, Ill.
Matsch, L. W. (Member), Commonwealth Edison Company, Chicago, Ill.
McNamara, B. F., Insulation Manufacturers Corporation, Chicago, Ill.
Oman, H., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Lambert, R. H., Allis-Chalmers Manufacturing Company, West Allis, Wis.
Petersen, F. H., Commonwealth Edison Company, Chicago, Ill.
Petersen, H. A., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Refer, L. W., Carnegie-Illinois Steel Corporation, Chicago, Ill.
Rice, D. N., Harnischfeger Corporation, Milwaukee, Wisconsin.
Rieke, C. R. (Member), Commonwealth Edison Company, Chicago, Ill.
Sagendorph, A. L. (Member), Commonwealth Edison Company, Chicago, Illinois.
Stone, C. B., Stone, Stafford, and Stone, Indianapolis, Indiana.
Swanson, A. R., General Electric X-ray Corporation, Chicago, Ill.
Swenson, L. M., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Taylor, D. W., Public Service Company of Northern Illinois, Evanston, Ill.
Tolentino, J. G., Electrical Engineers Equipment Company, Melrose Park, Illinois.
Webb, H. E., Jr., Chrysler Corporation, Highland Park, Michigan.
Weston, A. H., Chicago District Electric Generating Corporation, Hammond, Indiana.
Wold, E. A., Western Union Telegraph Company, Minneapolis, Minn.

6. North Central

Paynter, T. E., Colorado School of Mines, Golden, Colo.
Sheldon, M. T., Central Electric and Telephone Company, Woonsocket, So. Dakota.

7. South West

Boyer, O. A., Western Union Telegraph Company, Sweetwater, Texas.
Brown, R. B., Southwestern Bell Telephone Company, Oklahoma City, Okla.
Fairchild, R. J., A. Y. Taylor and Company, Clayton, Mo.
Fryer, R. T., Westinghouse Electric and Manufacturing Company, St. Louis, Mo.
Garlow, G. D., Southwestern Bell Telephone Company, Oklahoma City, Okla.
Halferty, C. W., Kansas Gas and Electric Company, Wichita, Kans.
Jenner, J. W., Shelley Electric Company, Wichita, Kans.
King, D. B., Oklahoma Power and Water Company, Sand Springs, Okla.
Lebens, J. C., Jr., Bussmann Manufacturing Company, St. Louis, Mo.
McNicol, J. E., Kansas Gas and Electric Company, Wichita, Kans.
Pitts, A. R., Oklahoma Gas and Electric Company, Ardmore, Okla.
Ross, L. L., Kansas Gas and Electric Company, Wichita, Kans.
Roush, G. E., United States Army, Signal Corps, Fort Riley, Kans.
Scott, R. B., General Electric Company, Kansas City, Mo.
Spehr, C. J., 218 East Fifth Street, Hoisington, Kans.
Weckel, M. F., Kansas Gas and Electric Company, Wichita, Kans.
Wilkins, J. D., White-Rodgers Electric Company, St. Louis, Mo.

8. Pacific

Bonner, H. W., Victor Equipment Company, San Francisco, Calif.
Janssen, R. R., North American Aviation, Incorporated, Inglewood, Calif.
Jordan, H., Trumbull Manufacturing Company, Los Angeles, Calif.
Mirk, A., Bethlehem Steel Company, San Francisco, California.
Strum, F. L., United States Army, Fort Baker, Calif.
Varney, B. F., North American Aviation, Incorporated, Inglewood, Calif.

9. North West

Anderson, J. W., Bonneville Power Administration, Portland, Ore.
Carlstad, A., Public Utility District No. 1, Wahkiakum County, Cathlamet, Wash.
Dean, R. V., Mountain States Telephone and Telegraph Company, Helena, Mont.
Lyckseth, J. M., Puget Sound Navy Yard, Bremerton, Wash.
McConnell, G. B., Mountain States Telephone and Telegraph Company, Boise, Idaho.

10. Canada

Brace, G. A. (Member), Ferranti Electric Limited, Toronto, Ont.
Kirkland, W. D., Hydro Electric Power Commission, Toronto, Ont.
Knudsen, P. D., Imperial Oil Limited, Toronto, Ont.
Turnbull, A. G. (Member), Canadian General Electric Company, Toronto, Ont.

Total, United States and Canada, 201

Elsewhere

Lythall, R. T., Johnson and Phillips, Limited, London, S.E. 7, England.

Total, elsewhere, 1

Of Current Interest

Concerning National Defense

The following news items, relating to various aspects of national defense activity, are grouped here for convenience.

WESTINGHOUSE REPORTS DEFENSE PRODUCTION

National defense accounted directly or indirectly for more than 40 per cent of the estimated $390,000,000 worth of new business done by the Westinghouse Electric and Manufacturing Company in 1940, according to a year-end summary issued by the company. About $23,000,000 was authorized for expansion of plant and equipment during the year, with $9,000,000 more authorized for 1941. Employment increased from 49,519 to more than 56,000 in 1940. Principal expansions of Westinghouse facilities for defense purposes occured at the steam division, South Philadelphia, Pa., which manufactures propulsion equipment for the United States Navy; at the radio division, Baltimore, Md., to increase production of radio equipment for Government orders; and at the lighting division, Cleveland, Ohio, to increase output of lighting and electrostatic air cleaning equipment for industries in defense production as well as for Government requirements. In addition, the company is constructing a $5,000,000 gun equipment plant near Louisville, Ky., which it will build and operate for the Navy under a leasing arrangement.

TOOL ENGINEERS CO-OPERATE

Needs in all branches of the defense program will be emphasized at the forthcoming Machine Tool and Progress Exhibition, to be held at Detroit, Mich., March 25–29, 1941, in connection with the annual convention of the American Society of Tool Engineers. A special aeronautical exhibition and technical session are included. The theme of the convention is to be "education for national defense," with special consideration of the problem of securing skilled labor.

Local chapters of the ASTE are organizing educational committees to co-operate with manufacturing plants and schools in their areas in training apprentice mechanics, particularly for defense jobs, the society has announced.

HOUSING AND DEFENSE

That the private building industry has the capacity to provide most of the housing needs of the defense program, but that an immediate plan of action is essential, were basic findings of a survey "Housing for Defense," made by Miles L. Colean for the Twentieth Century Fund, and published November 8, 1940. The report recommended that Government policy encourage private building effort, entering into direct housing operation only on good evidence that private means cannot meet the need, but warned that some such situations will occur. It recommended extension of financing facilities by the Government. The survey showed the great need to be for low-cost housing, and recommended permanent, rather than temporary construction to meet the need. With a plan for coordinating housing with the defense program, emphasizing selective location for defense industries, many of the mistakes and delays which seriously impaired defense efforts during the World War could be avoided, the report declared.

DEFENSE AND EMPLOYMENT

Factory employment in New York State during November 1940 rose above 1929 levels for the first time, according to the preliminary 1940 report of the state labor department. Placements during the first nine months of 1940 showed a gain of 58 per cent over 1939 for all private industry; of more than 100 per cent for factory employment. Reflecting defense activity, the greatest demand is for skilled workers. Training programs are being set up in which vocational schools and factories are participating. The state employment service endeavors to meet the demand, not only by classifying workers' skills, but by asking employers to anticipate their labor needs, and if a shortage exists, recruiting workers for training.

Positions to Be Filled Through Civil Service Examination

Notice of the following positions, which will be filled through civil service examinations, is published here as a service to members of the Institute. Application forms and full information as to requirements for examinations may be obtained from the secretary of the Board of United States Civil Service Examiners at any first- or second-class post office, or from the United States Civil Service Commission, Washington, D. C.

Engineering draftsmen. Salaries range from $1,620 to $2,600 a year, less 3½ per cent retirement deduction. Applicants may qualify in architectural, civil, electrical, heating and ventilating, lithographic, mechanical, plumbing, radio, structural, topographic, and other branches, except aeronautical, ordnance, or ship, which are covered by a previously announced examination. High-school education except for substituted drafting experience is required. Applicants must also show paid drafting-room experience, or completion of drafting course in a school specializing in drafting, or college engineering or architectural study; also experience in the branch chosen. Completion of advanced engineering or architectural study may be substituted for part of drafting training or experience. Written test not required; applicants will be rated on applications and corroborative evidence. Applications will be accepted until December 31, 1941.

Metallurgists and metallurgical engineers, various grades. For positions in the United States Bureau of Mines in connection with the national defense program for development of strategic metals. Salaries range from $3,200 to $5,600 a year, less 3½ per cent retirement deduction. Applicants must have completed a four-year college course with major study in chemistry, geology, mining, physics, engineering, or metallurgy, and have had responsible experience in metallurgy or metallurgical engineering. For the associate grade graduate study of specific value in the branch in which the applicant wishes to be rated may be substituted for the entire experience requirement; for the other grades a partial substitution may be made. No written test will be given. Applicants must not have passed their 60th birthday on the date of receipt of application.

Welding Research Committee Report

The welding research committee of Engineering Foundation has issued its annual report for 1940, in which are summarized the activities and achievements of its various divisions for the year. The report was published as a supplement to the *Journal* of the American Welding Society for December 1940.

The welding research committee was organized by Foundation in 1935, and its work has been sponsored jointly by the American Welding Society and the AIEE for the purpose of "assembling, digesting, and publishing all available information regarding welding research; stimulating and conducting needed research in the welding field; and correlating existing and future programs of welding research." Its activities have been conducted by three divisions: literature, fundamental research, and industrial research. C. A. Adams (A'94, F'13) consulting engineer of the E. G. Budd Manufacturing Company, Philadelphia, Pa., and a past president of the AIEE, is chairman of the committee; H. C. Boardman, director of research of the Chicago Bridge and Iron Company, Chicago, Ill., is vice-chairman; and W. Spraragen (A'17, M'26) technical secretary and editor of the American Welding Society, New York, N. Y., is executive secretary. Outstanding in the accomplishments of the committee during the year was the broadening of the base of support for its work. In 1939 the number of subscribing organizations and companies was 37; during 1940 the number increased to 63.

The work of the literature division consists of the preparation of reviews of welding literature, and during 1940 10 new reviews were published, bringing the total number published to 46. Several additional reviews are nearing completion. The more important reviews published during the year dealt with: welding of special metals; effect of certain ingredients in steel on the weldability; oxygen cutting of steel and oxygen-cutting procedure; flame cutting of nonferrous metals; resistance welding of aluminum and its alloys; welding magnesium and its alloys; and welding nickel and its alloys.

Activities of the fundamental research division are concerned primarily with broadening the knowledge of the fundamental factors controlling welding processes and governing welding applications. Research grants from funds of the division were made

to five universities; three of these were for work on resistance welding.

The basic philosophy of the industrial research division is "to stimulate needed research by governmental departments and corporations, and to initiate, organize, and carry out co-operative research projects." These projects are divided into two general types: those relating to materials, and those dealing with specific subjects of broad general interest and importance. During 1940, work was progressing on 12 projects, each under jurisdiction of a separate committee. Outstanding accomplishments of this division during the year consisted of the financing of three large research projects dealing with: the weldability of steels and the effect of carbon manganese on weldability; structural welding research; and resistance (aeronautical) research.

Early Home of GE Research Laboratory, Founded 40 Years Ago

THE General Electric Research Laboratory, 40th anniversary of which was commemorated at Schenectady, N. Y., December 17, 1940, occupied the building shown here early in 1901, after fire destroyed its first home in a barn at C. P. Steinmetz's residence. The laboratory now occupies two large buildings. It has had only two directors in its 40 years: Willis P. Whitney (A'01) now retired, and W. D. Coolidge (A'10, M'34), both AIEE Edison medalists. Speakers at the banquet celebrating the 40th anniversary of the laboratory's founding were Charles E. Wilson, president, General Electric Company; Doctor Karl T. Compton (F'31) president, Massachusetts Institute of Technology; and Samuel Ferguson (A'02) president, Hartford (Conn.) Electric Light Company, who was the first engineer of the laboratory.

Industry • • • •

Revere Award Announced for Workmen's Defense Ideas

Ten awards totaling $10,000 have been offered by Revere Copper and Brass Incorporated for the ten best suggestions for speeding national defense submitted by workers in the American metal working industry. It is estimated that more than 2,000,000 foremen, subforemen, and workmen are eligible to compete for the awards, which range from a $5,000 first prize to $250. All ideas remain the property of the men who submit them, whether or not they win prizes. Awards will be made by a jury with the following members:

Henry Heald, president, Illinois Institute of Technology

Admiral Joseph Strauss, United States Navy, retired

Major General Frank Parker, United States Army, retired

Robert Watt, former American labor delegate to the International Labor Congress

C. Donald Dallas, president, Revere Brass and Copper Incorporated

Light as Sabotage Protection

The need of protection against sabotage, recognized by many privately owned utility and industrial plants, should not be ignored by municipally owned public services, according to A. F. Dickerson, manager, lighting division, General Electric Company, Schenectady, N. Y. He presents the following pointers on the use of protective lighting to avoid sabotage:

1. Plan protective lighting for the worst possible visibility conditions.

2. If there is glare, be sure it blinds the intruder, not the guards.

3. Do not create shadowed areas.

4. Put more light around the boundary of a property or at distant points if the guards are located in well-lighted areas.

5. Keep all backgrounds as light as possible; paint fences and buildings in light colors.

6. Plan area lighting so that some light is contributed to any one point from more than one source.

7. Direct light across highways, streets, railroads, and navigable waterways so that glare or brightness will not prove a hazard to traffic.

8. Keep as much of the lighting equipment as possible well within the property.

Infrared Institute. The Fostoria Pressed Steel Corporation, Fostoria, Ohio, manufacturer of near-infrared equipment for baking, drying, dehydrating, and other operations, holds classes and laboratory demonstrations on the theory and practice of near-infrared applications, to provide accurate information for representatives of paint and enamel companies, conveyor makers, central station power salesmen, and others. Classes at the Near-Infrared Institute are held for two days each month and are open without charge to anyone interested.

Clean Air for Machines. Air from which more than 85 per cent of the dirt particles has been removed by 56 Precipitron cells is supplied to the newly installed Westinghouse 20,000-kva synchronous condenser of the Ohio Edison Company. This is reported to be the first application of electrostatic air cleaning to power-plant machinery.

H. L. Hibbard Dies. Harry Lyman Hibbard, retired manager of the marine department of Cutler-Hammer Manufacturing Company, died December 28, 1940, at Akron, Ohio. A native (1876) of Akron, he received the degree of mechanical engineer from Cornell University in 1899. He engaged in electrical work at the Newport News (Va.) Shipbuilding and Drydock Company and for the Navy Department, Washington, D. C., before going with Cutler-Hammer in 1907 to organize its marine work. He continued with the company until his retirement in 1932. He became an Associate of the AIEE in 1907 and Fellow in 1921, and was active on the marine and standards committees, prior to his resignment in 1934.

GE Expands Plastics Department. General Electric Company has announced plans to expend approximately $400,000 on expansion of the eastern facilities of the Plastics Department. A new building and added equipment at Pittsfield, Mass., will account for 75 per cent of the expenditure; the remainder will provide a new building and presses at Meriden, Conn., and installation of a new press at Lynn, Mass.

Education • • •

Defense Courses Announced by Engineering Colleges

Approval of 444 engineering defense training courses, given by 91 engineering colleges in 44 states, the District of Columbia, and Puerto Rico, has been announced to date by the United States Office of Educa-

tion. These short intensive courses are financed under the $9,000,000 program initiated in October 1940 (*EE, Dec. '40, p. 521–2*) to meet the shortage of engineers for service with the industries and government agencies engaged in national defense, the announcement states.

Acceptance of the proposals submitted by the individual colleges is based upon demonstration by the school that there is a definite defense need for the men to be trained, that it has the experience and facilities to give the instruction at reasonable cost, and that a sufficient number of qualified students are available, according to the United States Office of Education. Applicants are considered by the colleges individually; tuition for those accepted is paid by the Federal Government. While placement is not guaranteed, the fact that courses are aimed at recognized needs for specially trained personnel indicates that jobs will be available, the report states, pointing out that the United States Civil Service Commission, Federal and state employment services, and college placement bureaus will assist those completing the courses to find jobs.

Engineering Journalism at Cornell. A course in engineering journalism has been inaugurated at Cornell University to give technical instruction in editorial procedures and business methods to the staff of the *Cornell Engineer*. The section for editors will cover writing of technical articles, copy editing, proofreading, make-up and other procedures; that for members of the business staff will cover accounting, advertising, circulation problems, and other aspects of publication management. Staff members may take the course for two years, with a maximum of four hours credit.

NYU Teaches Research Laboratory Management. What is believed to be the first course in the United States in research laboratory management is being offered by New York University, beginning in February 1941. The rapid development of industrial research and its growing importance in the national defense program have produced a need for trained administrative personnel. The course is being planned in collaboration with an advisory committee headed by Maurice Holland (A'23, M'30) director of the division of engineering and industrial research, National Research Council.

More Jobs for Columbia Graduates. Positions offered men students graduating from Columbia University in 1940 showed an increase of 28 per cent over the preceding year, according to a recent report of the University appointments secretary. Nearly 100 per cent of the engineering, physics, and chemistry students were placed before commencement in 1940. The requirements of national defense, as well as increased recruiting by industrial companies, largely account for the gain, the report said.

High-Voltage Laboratory at Cornell. Construction of a new $150,000 high-voltage laboratory for the Cornell University College of Engineering has been authorized by the board of trustees of the University. The building, of steel construction, will be connected with a half-mile high-voltage transmission line. It will contain both 60-cycle and impulse-testing equipment, the former capable of providing 750,000 volts single phase or 433,000 volts three phase, and the latter capable of simulating lightning up to 3,000,000 volts. The laboratory will be used for research into the properties of air and other electrical insulating materials, and for testing apparatus for commercial purposes.

Honors • • • •

J. V. N. Dorr Receives Perkin Medal

The Perkin Medal, awarded annually for valuable work in applied chemistry, by the American section of the Society of Chemical Industry, has been conferred for 1940 upon Doctor J. V. N. Dorr, president, The Dorr Company, Inc. The award was made January 10, 1941, at a joint meeting with the American Chemical Society, American Institute of Chemical Engineers, Electrochemical Society, and Société de Chimie Industrielle.

Doctor Dorr is a native (1872) of Newark, N. J., and received the degree of bachelor of science from Rutgers University in 1894. He also has been awarded honorary degrees from that and other institutions. He spent some time as chemical experimenter in the laboratories of Thomas A. Edison, and was employed as assayer and chemist by several mining companies, before developing the group of important industrial inventions for which he is known. He organized The Dorr Company, of which he is president. He is a past president of United Engineering Trustees, Inc., and of the American Institute of Chemical Engineers, and has received the James Douglas Medal of the American Institute of Mining and Metallurgical Engineers, the Chemical Industry Medal, and one of the national "modern pioneer" awards of the National Association of Manufacturers.

Library • • • •

OPERATED jointly by the AIEE and the other founder societies, the Engineering Societies Library, 29 West 39th Street, New York, N. Y., offers a wide variety of services to members all over the world. Information about these services may be obtained on inquiry to the director.

Bibliography on Airplane Hangars

Current interest in all matters connected with aviation has prompted the Engineering Societies Library to prepare a list of references on the design and construction of airplane hangars. The list includes 100 articles selected from those published during the years 1928–40 in leading domestic and foreign periodicals, and contains material on both steel and reinforced-concrete structures.

Copies may be obtained by sending $2 to Engineering Societies Library, 29 West 39th Street, New York, N. Y.

Other Societies •

AAAS Elects Langmuir

At the annual meeting of the American Association for the Advancement of Science, held at Philadelphia, Pa., December 27, 1940, to January 2, 1941, Doctor Irving Langmuir, research chemist, General Electric Company, Schenectady, N. Y., was elected president of the Association for the coming year. A native (1881) of Brooklyn, N. Y., Doctor Langmuir received the degrees of metallurgical engineer from Columbia University in 1903, and of master of arts and doctor of philosophy from the University of Gottingen in 1906, and has been awarded honorary doctor's degree by a number of institutions in the United States and other countries. He was an instructor in chemistry at Stevens Institute of Technology, Hoboken, N. J., before joining the General Electric Research Laboratory in 1909. Among his achievements are the development of the gas-filled tungsten lamp, electron discharge apparatus, the condensation high-vacuum pump, and atomic hydrogen welding. His honors include the Nobel Prize for chemistry (1932); the Hughes Medal of the Royal Society, London; the Rumford Medal, and many others. He is a member of many scientific and technical societies in the United States and in other countries.

ASA Reports 1940 Activities

Complete revision of the National Electrical Code was one of the important activities of the American Standards Association during 1940, as reported at its annual meeting December 11, 1940. (Details of the revised code appeared in "Some Notes of the National Electrical Code", by Alvah Small, ELECTRICAL ENGINEERING, December 1940, pages 503–04.) Revision of the National Electrical Safety Code is also under

Future Meetings of Other Societies

American Chemical Society. April 7–11, 1941, St. Louis, Mo.

American Institute of Chemical Engineers. Semi-annual meeting, May 19–21, 1941, Chicago, Ill.

American Institute of Mining and Metallurgical Engineers. Annual meeting, February 17–20, 1941, New York, N. Y.

American Physical Society. 240th meeting, February 21–22, 1941, Cambridge, Mass.

241st meeting, May 1–3, 1941, Washington, D. C.

American Railway Engineering Association. Annual meeting, March 11–13, 1941, Chicago, Ill.

American Society for Testing Materials. Spring meeting, March 3–7, 1941, Washington, D. C.

American Society of Civil Engineers. Spring meeting, April 23–25, 1941, Baltimore, Md.

American Society of Mechanical Engineers. Spring meeting, April 1–3, 1941, Atlanta, Ga.

Electrochemical Society. Spring meeting, April 16–19, 1941, Cleveland, Ohio.

Midwest Power Conference. April 9–10, 1941, Chicago, Ill.

National Electrical Manufacturers Association. February 17–21, Chicago, Ill.

May 11–15, 1941, Hot Springs, Va.

way, four sections having been redrafted during the past year.

Other ASA activities during 1940 included a new standard for rounding off numerical values, one completed standard for photographic equipment and progress on several others, a group of standards for gas appliances, further progress on prevention of occupational diseases and on standards for consumer goods, and authorization of four new safety projects. During the year 73 standards were approved.

Requirements of the national defense program are expected to cause emphasis on undertakings vital to defense and on related safety codes during the coming year according to Retiring President E. A. Prentis.

R. F. Zimmerman, vice-president, United States Steel Corporation, and former vice-president, ASA, was elected president for the coming year. R. P. Anderson, American Petroleum Institute, was re-elected chairman of the Standards Council, and H. S. Osborne (A'10, F'21), American Telephone and Telegraph Company, vice-chairman.

Chemical Society Acquires Building

The American Chemical Society has announced the purchase of a building at 16th and M Streets, NW, Washington, D. C., as national headquarters for the society. Rapid growth of the organization during 1940 is said to have rendered its present headquarters inadequate. The present membership is about 26,000 chemists and chemical engineers, according to the announcement.

Letters to the Editor • • •

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

A Transformation Extending the Use of Heaviside's Operational Calculus

To the Editor:

Messrs. Meyerhoff and Reed (*EE, Sept. '40, p. 385*) have extended the use of Heaviside's operational calculus to circuits in which the initial currents and charges are not zero, by introducing new variables which satisfy the initial rest requirement, then solving the problem in terms of these new variables, and finally returning to the actual currents of the circuit. A more straightforward method is available, however, which also places no restriction upon the initial conditions, which somewhat reduces the algebra involved, and which avoids the introduction of fictitious currents and charges. In the Laplacian transform method the initial conditions are introduced when the operational equations are written, and direct application of the Heaviside expansion theorem gives the final solution.

This method would be applied to the circuit considered by Meyerhoff and Reed as follows (see figure 1): Let the initial voltage across the capacitor be V, with signs as shown, and the initial current in the coil be $i_0 = i_1(0) - i_2(0)$. The differential equations for the two meshes are:

$$\left(L\frac{d}{dt}+R\right)i_1(t) - L\frac{d}{dt}i_2(t) = E \qquad (1)$$

$$-L\frac{d}{dt}i_1(t) + \left(L\frac{d}{dt}+\frac{1}{C}\int dt\right)i_2(t) = 0 \qquad (2)$$

Using the Laplacian transformation the "operational" equations are

$$(Ls+R)I_1(s) - LsI_2(s) = \frac{E}{s} + L[i_1(0) - i_2(0)] = \frac{E}{s} + Li_0 \qquad (3)$$

$$-LsI_1(s) + \left(Ls+\frac{1}{Cs}\right)I_2(s) = \frac{V}{s} - Li_0 \qquad (4)$$

in which the complex variable s appears in place of the operator ϕ and the transform E/s in place of the step function $E1$. The initial conditions were automatically introduced in writing the transforms for the various terms, as follows:

$$\mathcal{L}[E1] = \frac{E}{s} \qquad (5)$$

$$\mathcal{L}[i(t)] = I(s) \qquad (6)$$

$$\mathcal{L}\left[L\frac{d}{dt}i(t)\right] = LsI(s) - Li(0) \qquad (7)$$

$$\mathcal{L}\left[\frac{1}{C}\int i(t)dt\right] = \frac{1}{Cs}I(s) + \frac{q(0)}{Cs} = \frac{1}{Cs}I(s) - \frac{V(0)}{s} \qquad (8)$$

Examination of equations 3 and 4 will show that they can be written directly from inspection of the circuit. The right-hand member of each is the sum of all the initial flux-linkages in the direction of the mesh current, plus $1/s$ times the sum of all the initial capacitor voltage rises, plus the transforms of any excitation voltages appearing in the mesh. The entire right-hand members are sometimes called the "loop excitation functions" to correspond with the self and mutual "loop impedance functions" which appear in the terms of the left-hand members of the equations.

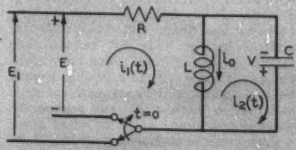

Figure 1

Solving equations 3 and 4 gives

$$I_1(s) = \frac{(E+V)s^2 + \frac{i_0}{C}s + \frac{E}{LC}}{R\left(s^2 + \frac{1}{RC}s + \frac{1}{LC}\right)}\,\frac{1}{s} \qquad (9)$$

$$I_2(s) = \frac{(E+V-Ri_0)s^2 + RVs}{R\left(s^2 + \frac{1}{RC}s + \frac{1}{LC}\right)}\,\frac{1}{s} \qquad (10)$$

Here the factor $1/s$ is written separately to emphasize the similarity to the usual notation where the unit function 1 would appear. Direct application of the expansion theorem gives

$$i_1(t) = \frac{E}{R} + \frac{1}{R}\epsilon^{-\alpha t}\left[V\cos\omega t + \frac{Ri_0 - E - \frac{V}{2}}{CR\omega}\sin\omega t\right] \qquad (11)$$

$$i_2(t) = \epsilon^{-\alpha t}\left[\frac{E+V-Ri_0}{R}\cos\omega t + \frac{Ri_0 + V\left(\frac{2R^2C}{L}-1\right) - E}{2R^2C\omega}\sin\omega t\right] \qquad (12)$$

in which

$$\alpha = \frac{1}{2RC}$$

and

$$\omega = \sqrt{\left(\frac{1}{LC}\right)^2 - \left(\frac{1}{2RC}\right)^2}$$

These are the expressions given by Meyerhoff and Reed except for the correction of the typographical error in their value of ω. (It will be noted that in figure 1 of their letter the arrow on V_c indicates the direction of voltage drop, while the arrow on E shows the direction of voltage rise.)

The Laplacian transform method possesses all the advantages of the Heaviside operational calculus and is in fact the same wherever the latter applies. The Laplacian method, however, allows a little more direct approach to certain problems, especially those involving initial conditions, excitation by voltages other than constant direct current applied at $t=0$, and impulsive responses. It is subject to no restrictions which do not apply also to the usual operational method and notation. A short review of the Laplacian transform method is given on page 2-108 of Eshbach's "Handbook of Engineering Fundamentals" (John Wiley, 1936) and a more complete summary and bibliography in a paper by M. G. Malti (*EE, Nov. '35, p. 1222-7*) and especially in the discussions thereof (*EE, July '36, p. 826-30*).

PAUL L. MORTON (A'33)

(Instructor in electrical engineering, University of California, Berkeley)

Hyperbolic Functions of Complex Variables

To the Editor:

Most students, and not a few mature engineers, are bothered by their inability to grasp the physical significance or geometric interpretation of the hyperbolic functions of complex variables that are encountered in transmission-line theory. Trigonometric and hyperbolic functions of real variables may be visualized in relation to circles or hyperbolas but the same concepts are inadequate when dealing with complex variables. After all, it is difficult to visualize a "complex angle". A simple and useful interpretation of these hyperbolic functions may be gained from their equivalent exponential forms plus the physical significance of these exponential quantities in the transmission-line theory. It is hoped that this interpretation may be found useful by those engineers who must always "see a picture of things".

Both the trigonometric and hyperbolic cosines may be represented by the same general exponential form

$$\frac{\epsilon^{\gamma}+\epsilon^{-\gamma}}{2} \qquad (1)$$

For real variables, the only difference between these two functions is that for the hyperbolic cosine γ is a real quantity, while for the trigonometric cosine γ is a pure imaginary quantity. Sometimes it is claimed that this exponential expression for the cosine lacks physical significance, but this criticism does not seem justified in view of the very lucid interpretation which has been presented in a recent text.* This interpretation will be outlined briefly, as it forms the basis for the present interpretation of hyperbolic functions of complex variables.

The relations

$$\epsilon^{j\omega t} = \cos \omega t + j \sin \omega t \qquad (2)$$

and

$$\epsilon^{-j\omega t} = \cos \omega t - j \sin \omega t \qquad (3)$$

are well known in electrical engineering. $\epsilon^{j\omega t}$ is merely a unit vector in the complex plane, rotating in a positive (counterclockwise) direction with an angular velocity of ω radians per second. At any instant, its projection on the real axis is $\cos \omega t$ and its projection on the imaginary axis is $\sin \omega t$. The square root of the sum of the squares of these real and imaginary components gives the magnitude of the vector and always must equal unity. Similarly, $\epsilon^{-j\omega t}$ may be interpreted as another unit vector rotating in the negative (clockwise) direction with the same angular velocity.

Since

$$\cos \omega t = \frac{\epsilon^{j\omega t}+\epsilon^{-j\omega t}}{2} \qquad (4)$$

the cosine is given by half the sum of these two vectors which rotate in opposite directions. This is illustrated by figure 1, which shows that the imaginary components of these two vectors always cancel each other, while their real components add to generate the familiar cosine wave. This is merely a graphical addition of equations 2 and 3.

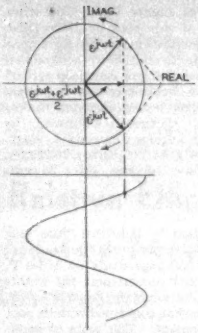

Figure 1

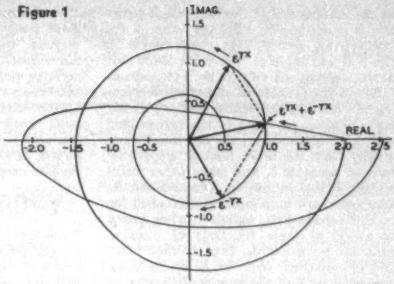

Figure 2

For complex variables

$$\cosh\ (\alpha+j\beta)x = \frac{\epsilon^{(\alpha+j\beta)x}+\epsilon^{-(\alpha+j\beta)x}}{2} = \frac{\epsilon^{\alpha x}\epsilon^{j\beta x}+\epsilon^{-\alpha x}\epsilon^{-j\beta x}}{2} \qquad (5)$$

In this, $\epsilon^{(\alpha+j\beta)x}$ is a rotating vector whose length increases exponentially according to $\epsilon^{\alpha x}$ and whose direction is given by $\epsilon^{j\beta x}$. Consequently, the locus of this vector is an exponentially increasing spiral in the complex plane, starting from the point $1+j0$, when x is zero. Similarly, $\epsilon^{-(\alpha+j\beta)x}$ rotates in the negative direction and its length decreases exponentially. Its locus is an exponentially decaying spiral.

Figure 2 shows the graphical addition of these two vectors. Unlike figure 1, the locus of the sum of these two vectors does not follow the real axis, because their imaginary components no longer cancel each other completely. The locus of the sum, $2\cosh(\alpha+j\beta)x$ starts from $2+j0$ and gradually approaches the locus of $\epsilon^{(\alpha+j\beta)x}$ as $\epsilon^{-(\alpha+j\beta)x}$ vanishes for large values of x. The locus of the hyperbolic cosine, which is half this sum, has the same shape but only half the magnitude.

For the hyperbolic sine

$$\sinh\ (\alpha+j\beta)x = \frac{\epsilon^{(\alpha+j\beta)x}-\epsilon^{-(\alpha+j\beta)x}}{2} \qquad (6)$$

A similar construction may be employed to give the locus of the difference of these two vectors, as shown in figure 3. The subtraction is performed by first forming the negative of the decaying vector, by a 180-degree rotation, and adding this to the expanding vector. The locus starts from the origin and again approaches $\epsilon^{(\alpha+j\beta)x}$ as $\epsilon^{-(\alpha+j\beta)x}$ vanishes.

Other hyperbolic functions, such as the hyperbolic tangent, are defined in terms of these two basic functions, so need not be considered here.

The remaining step is to show the correlation between transmission-line theory and these exponential loci. The voltage at any point along the line is given by

$$E = E_s \cosh \gamma x - I_s Z_0 \sinh \gamma x \qquad (7)$$

where E is the vector voltage, $E_m \epsilon^{j\omega t}$, at any point x miles from the sending end of the line. E_s and I_s are the vector voltage and current at the sending end of the line. Z_0 is the characteristic impedance of the line. γ is the propagation constant, given by

$$\gamma = \alpha + j\beta \qquad (8)$$

where α is the attenuation constant in nepiers per mile and β is the phase constant in radians per mile.

Throwing equation 7 into its exponential form and collecting terms,

$$E = \frac{E_s+I_sZ_0}{2}\epsilon^{-(\alpha+j\beta)x} + \frac{E_s-I_sZ_0}{2}\epsilon^{(\alpha+j\beta)x} \qquad (9)$$

This shows that the voltage at any point along the line consists of the sum of a transmitted and a reflected voltage wave. The transmitted wave decreases exponentially from its sending-end value, $\frac{1}{2}(E_s+I_sZ_0)$, and its phase angle lags that of the sending-end voltage by $-\beta x$ radians. The reflected wave increases exponentially with distance from the sending end, which is equivalent to saying that it decreases exponentially with distance from the receiving end of the line, its point of origin. This reflected wave has a value $\frac{1}{2}(E_s-I_sZ_0)$

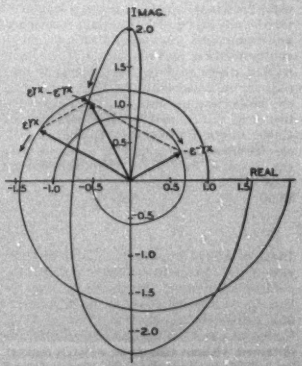

Figure 3

*Electric Circuits, Members of the Staff, Department of Electrical Engineering, Massachusetts Institute of Technology. John Wiley and Sons, Inc., New York, N. Y., 1940, pages 203–07.

at the sending end of the line, which generally is much smaller than the value of the transmitted wave. The phase angle of the reflected wave at any point leads that of the sending end voltage by $+\beta x$ radians.

This exponential form of the transmission-line voltage equation lends itself to physical interpretation in terms of the transmitted and reflected waves on the line much more readily than the more familiar hyperbolic form of equation 7, and many other interesting conclusions may be obtained from it. The hyperbolic form is more convenient for making calculations, especially when tables or charts of these functions of complex variables are available, because each function is multiplied only by E_r or by I_rZ_0 instead of by half the sum or difference of these complex voltages. In other words, the general acceptance of the hyperbolic form of the transmission equations probably has resulted rather from reasons of mathematical expediency than as an aid to their physical interpretation in terms of reflection phenomena.

Even so, equation 5 shows that $\cosh(\alpha+j\beta)x$ may be regarded as half the sum of a reflected wave $\epsilon^{(\alpha+j\beta)x}$ and a transmitted wave $\epsilon^{-(\alpha+j\beta)x}$, these waves being equal when x is zero. Similarly, equation 6 may be regarded as half the difference between these reflected and transmitted waves. The graphical interpretations given in figures 2 and 3 therefore may be regarded as simple vector diagrams showing the loci of the sums and differences of reflected and transmitted waves which happen to be equal at the sending end of a line, where x is zero.

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(Naval Research Laboratory, Washington, D. C.)

Books Received •

Modern Plastics Catalog, 1941. The 1941 catalog and directory published by *Modern Plastics* magazine endeavors to present complete information on all phases of the plastics industry. Issued for the first time in its present form, the volume is divided into eight sections: plastics engineering, materials, molding and fabricating, machinery and equipment, laminates, plastic coatings, synthetic fibers, and an index and directory section which includes a bibliography and chapter on nomenclature. Charts on plastics properties, solvents, and plasticizers are included, the latter two for the first time. Copies of the 476-page 9-by-12 volume with special plastics cover may be obtained from the Breskin Publishing Corporation, 122 East 42d Street, New York, N. Y.; price $3.50.

Index to ASTM Standards. The latest edition of the "Index to ASTM Standards, Including Tentative Standards," recently issued, contains information on the society's 952 standards as of December 1, 1940. Copies of the 172-page publication may be obtained without charge on written request to ASTM headquarters, 260 South Broad Street, Philadelphia, Pa.

"Rural America Lights Up." The stipulated purpose of this book by Harry Slattery, is "to describe the evolution of rural electrification in its relation to the economic security and well being of American agricultural life; not neglecting the important part it must play in any program dealing with national defense." Published by National Home Library Foundation, Washington, D. C.; 4½ by 7¼ inches, 142 pages, flexible cardboard binding; price 25 cents copy.

"Cadiz to Cathay". Subtitled "the long struggle for a waterway across the American isthmus", this 550-page study by Miles P. DuVal traces and reconstructs the events leading to the creation of the Panama Canal, crediting each nation concerned with its part in that development. The texts of pertinent treaties are appended, and there is a reference list of official and general publications and other material. Stanford University Press, Stanford University, Calif., price $5.00.

"Little Bits About Big Men". Anecdotes about business leaders and men in public life which were collected by B. C. Forbes through personal acquaintance or during interviews are assembled in this volume. Among those mentioned are many well-known Institute members. B. C. Forbes Publishing Company, New York, N. Y.; price $2.50.

"Unheeded Warnings". Newspaper contributions, addresses, and letters to the President and members of Congress by D. S. Snell (A'24) on international events and their relation to the future of the United States have been compiled in this volume, published by the author. Price per copy, $2.00.

The following new books are among those recently received at the engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

PRACTICAL DESIGN OF SMALL MOTORS AND TRANSFORMERS (Electrical Engineer Series, volume II). Edited by E. Molloy. Chemical Publishing Company, New York, 1940. 176 pages, illustrated, 8 by 5 inches, cloth, $2.00. Practical information on the design, construction, and rewinding of small motors, dynamos, and power transformers. The simplicity of the calculations and the many photographs, diagrams, and tables of working data make the book particularly useful to the general worker.

SCIENCE IN INDUSTRY. By A. M. Low. Oxford University Press, New York, 1939. 160 pages, illustrated, 9 by 5½ inches, cloth, $1.75. Describes some of the more important ways in which scientific discovery has influenced the course of industrial development and affected our ordinary life. Topics covered include refrigeration, metals, coal and its by-products, transport, and printing. For the general reader.

SOUND. By R. G. Richardson. Third edition. Longmans, Green and Company, New York; Edward Arnold and Company, London, 1940. 339 pages, diagrams, etc., 8½ by 5½ inches, cloth, $5.25. Attempts to give the student the results of recent experimental research, and should be useful to research workers for reference, for it supplements the descriptions of important work by copious reference to original papers. This edition has been carefully revised, especially in the chapters upon impedance, supersonics, and sound reproduction.

TABLES OF SINES AND COSINES FOR RADIAN ARGUMENTS. Prepared by the Federal Works Agency, Works Project Administration for the City of New York, as a report of Official Project No. 765-97-3-10; A. N. Lowan, technical director; conducted under the sponsorship of the National Bureau of Standards, Washington, D. C., 1940. 375 pages, tables, 11 by 8 inches, cloth, $2.00. The major part of this fourth volume of a special series of mathematical publications consists of a table of values of $\sin x$ and $\cos x$ to eight decimal places at intervals of 0.001 from 0.000 to 25.000. Supplementary tables give values of $\sin x$ and $\cos x$ to various numbers of decimal places for other ranges and intervals, values of $p(1-p)$, and conversion tables from radians to degrees and vice versa.

GEOPHYSICAL PROSPECTING FOR OIL. By L. L. Nettleton. McGraw-Hill Book Company, New York, 1940. 444 pages, illustrated, 9 by 6 inches, cloth, $5.00. While there is a voluminous periodical literature upon the subject, this appears to be the first connected presentation, in a single volume, of the principles and practice of modern oil prospecting by geophysical methods. Intended for students or lay readers, rather than for specialists, the subject matter selected and its presentation are based upon practical experience in the use of geophysical methods. Gravitational, magnetic, and seismic methods are discussed at length; electrical prospecting and well-logging methods, miscellaneous prospecting methods, and operations in wells described briefly. A section is devoted to interpretation of geophysical surveys.

TECHNICAL DRAFTING. A Text and Reference Book on Graphics. By C. H. Schumann. Harper and Brothers, New York and London, 1940. 793 pages, illustrated, 9½ by 6 inches, cloth, $3.50. Designed not only as a comprehensive textbook on engineering drafting but also as a professional reference book. The first part presents the elementary principles of the subject. The second part goes intensively into commercial practice in the various branches of engineering, including welded construction and both architectural and topographical drafting.

TECHNICAL DRAWING. By F. E. Giesecke, A. Mitchell, and H. C. Spencer. Second edition. Macmillan Company, New York, 1940. 687 pages, illustrated, 9 by 6 inches, cloth, $3.00. Covers the science of technical drawing, including such special applications as architectural and topographic work and the reproduction of drawings. Among several new chapters in this edition is one on welding representation. There are many practical examples and problems, and lists of symbols, data tables, specifications, and a bibliography are appended.

THE UNITED STATES PATENT SYSTEM. By J. A. Diemer. American Society for Metals, Cleveland, Ohio, 1940. 72 pages, diagrams, etc., 9 by 6 inches, fabrikoid, $1.00. Contains three lectures presented to the Chicago chapter of the American Society for Metals. The distinctive features of the United States patent system are described, reasons for their establishment and continued use presented, and controversial issues explained. Recent legislative activity is discussed. Bibliography.

TELEVISION TODAY AND TOMORROW. By S. A. Moseley and H. J. Barton-Chapple, with a foreword by J. L. Baird. Fifth edition. Pitman Publishing Corporation, New York, 1940. 179 pages, illustrated, 9 by 5½ inches, cloth, $3.00. The history of television is briefly reviewed, its general principles are discussed, and equipment and processes are described. The subject of big-screen television is considered at some length, and several special television methods likely to be of importance in the future are described. A glossary of terms is appended.

ATM (Archiv für technisches Messen). 107, 108, 109, 110; May, June, July, August 1940. R. Oldenbourg, Munich and Berlin, pages T49-T56, illustrated, May 12 by 8 inches; June, July, August, 12 by 8½ inches; paper, 1.50 rm each. Four numbers of a monthly publication containing classified articles upon various types of apparatus and methods for technical measurements. Certain numbers also contain descriptions of specific instruments manufactured by German companies.

MACRAE'S BLUE BOOK AND HENDRICK'S COMMERCIAL REGISTER. 48th edition, 1940–41. MacRae's Blue Book Company, Chicago and New York, 1940. 3,523 pages, illustrated, 11½ by 8 inches, cloth, $15.00. The new edition of this directory follows the plan of preceding ones. It includes an alphabetic list of manufacturers, producers, and wholesalers, with the addresses of branch offices; a minutely classified list of products, with an extensive index; a list of towns of 1,000 or more population, with their trade facilities and railroad connections; and a list of trade names.

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Transactions Section

Preprint of Corresponding Pages From the Current Annual Transactions Volume

Any discussion of these papers will appear in the June 1941 "Supplement to Electrical Engineering—Transactions Section"

A Comparison of the Relative Efficiency of the Schafer and Pole-Top Methods of Artificial Respiration

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THE pole-top method of artificial respiration was devised by E. W. Oesterreich[1] of the Duquesne Light Company, Pittsburgh, Pa., to give prompt aid in case of electric shock occurring while men are working on poles of power lines. When a worker receives an electric shock while working on a pole minutes elapse before he can be lowered to the ground and resuscitation started by the prone-pressure method. In the field, the elapsed time is seldom less than five minutes[2] and in many cases it is considerably longer. The pole-top method of resuscitation was developed to reduce this period. Tests have shown that an operator can reach a man working alone on a pole and start squeezing his abdomen within approximately one minute.[2] If there are two men on the pole and one receives a shock the elapsed time before the first pressure is applied is much shorter. While an operator is applying the pole-top method, other members of the line crew make preparation for lowering the victim to the ground where the prone-pressure method may be applied, should it prove necessary.

The results obtained in the field with the pole-top method were excellent, and in 1939 E. W. Oesterreich[2] reported 14 successful resuscitations out of 16 applications. This is an exceptionally fine record when compared with the reports of cases where artificial respiration was not started until the victims had been lowered to the ground.

At the request of the Duquesne Light Company a comprehensive study of the pole-top method was started in the fall of 1939 at The Johns Hopkins University. This is a joint investigation in which its schools of engineering, hygiene, and medicine are co-operating.

This paper presents a report of the first stage of the investigation and deals only with a comparison of the relative amounts of air moved by the standard Schafer prone-pressure method, the modified Schafer method, and the pole-top method.

Standard Schafer Method

The prone-pressure method of resuscitation was developed by E. A. Schafer[4] in 1907 and has been used widely. In applying this method the subject is placed on his abdomen, with one arm extended and the other bent at the elbow to support the face. The operator kneels, straddling one or both of the subject's thighs, and places his hands on the small of the back. With the arms held straight, the operator swings slowly forward and brings his weight to bear upon the patient. Then the operator swings back quickly so as to remove the pressure entirely. The hands are, however, kept in position on the subject's back. The operation is repeated 12 to 15 times a minute.

Modified Schafer Method

In the modified Schafer method of artificial respiration as employed in this investigation, the "snap-off"[3] method of removing the hands from the subject's back was used. The procedure is similar in every way to that described under the standard prone-pressure method except that the operator releases the pressure suddenly by rolling the palms of his hands outward and thus causing them to slip off the subject's back to the ground.

Pole-Top Method

At the present time the recommended procedure in the pole-top method[2] is as follows:

"1. The first man to reach the victim clears the body from electrical contact permitting the body to hang from the safety strap alongside the pole if possible.

"2. The rescuer then takes a position below the victim on the pole and after placing his safety strap around the pole, proceeds to work his way up with one leg of the victim on either side of his safety strap, and with the body of the victim between himself and the pole. When the safety strap is as high on the pole as can be reached, the weight of the victim's body is taken in a straddle position on the safety strap of the operator.

"3. The mouth of the victim is cleared of foreign substances, the tongue is pulled out and the head pushed forward toward the pole.

"4. The operator then encircles the waist of the victim (under arms) placing both hands, one from each side, on the abdomen of the victim, thumbs below the lower ribs and fingers touching.

Figure 1. Pole-top method of artificial respiration

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The authors wish to take this opportunity of thanking the Duquesne Light Company of Pittsburgh for funds for carrying on this research and the Consolidated Gas Electric Light and Power Company of Baltimore for furnishing equipment.

1. For all numbered references, see list at end of paper.

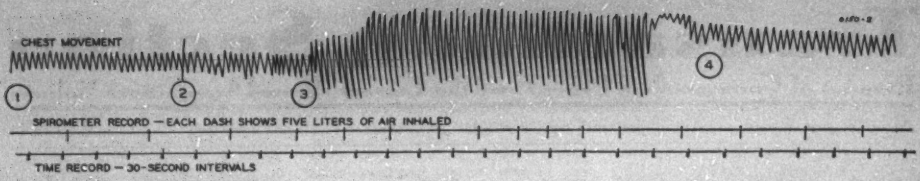

Figure 2. Record of Schafer prone-pressure test

(1) First control. (2) Second control. Operator straddling subject's thigh. (3) Artificial respiration. Note increased chest movement. (4) Final control

"5. The operator applies a constricting action with his arms and hands, obtaining a compression force in an upward direction on the upper abdominal region. At the finish of the stroke the hands should be cupped with the fingers depressing the abdomen under the breast bone. The pressure is then released and periodically reapplied at a frequency of 12–15 per minute until the victim regains consciousness or the resuscitation is to be discontinued."

Subjects

In carrying out this investigation volunteers were chosen from among the students and the staffs of the University. The 15 men tested ranged in age from 20 to 60 years and in weight from 125 to 211 pounds. Each subject is designated by a roman numeral.

All three methods of artificial respiration were applied to each subject. Repeat readings were also made on each man. The time interval that elapsed between successive observations of the same individual varied from five days to one or more weeks.

The results reported in this paper were obtained from men who possessed the ability to relax completely and to place themselves entirely in the hands of the operator. No drugs or anaesthetics were used in the work. Every effort was made to assure the subjects and to convince them by preliminary experiments and trials that there was nothing to fear and that all that was necessary on their part was passiveness. The apparatus was so arranged that they were not cognizant of the results obtained.

Apparatus

The subject breathed through a gas mask connected with a spirometer or gas meter which measured the amount of air inhaled. Each revolution of the spirometer corresponded to five liters of air. The amplitude of movement of the chest and the rate of respiration were recorded on a smoked drum by the change or pressure set up in a pneumograph strapped around the subject's chest. Each revolution of the spirometer and a time mark at 30-second intervals were recorded simultaneously with the record of the respirations. The drum was driven by a clockwork mechanism.

Experimental Procedure

In general, the experimental procedure employed with the Schafer methods was also used in the study of the pole-top method.

In the prone-pressure tests the subject lay face down on a thin mattress which was placed on the floor. With the gas mask on and the pneumograph in place the subject rested for at least ten minutes or until his breathing was regular and normal. The smoked drum was then started and a normal record of the man's breathing taken. Then the operator took his position straddling the subject's thigh. A second or control record of the respiration was taken after a short interval in order to determine if the operator had disturbed the normal rate and amplitude of the subject's breathing. If the two records were similar, then the operator proceeded to apply the designated method of artificial respiration. A complete record of the man's respirations and of the amount of air moved was taken during the period of artificial respiration, which was never continued for more than five minutes so as not to tire the subject.[6] Following the application of artificial respiration, a third control record was taken.

A section of a standard pole approximately ten feet in length was mounted in the laboratory. This was used in the pole-top method studies. The subject was seated on a safety belt which passed around the pole. The ends of the belt were held by a special pipe support in a position which simulated an operator holding the subject. This support was developed so as to relieve the operator of the work of supporting the subject's weight during the period of relaxation and rest.

The subject seated himself on this belt, and with the gas mask and pneumograph in place, rested until his breathing became regular and normal. This usually required about ten minutes. A short record of the subject's breathing was taken, then the operator climbed the pole and took the weight of the subject on his own safety belt. The pipe support was moved out of the way. Several minutes were then allowed to pass and a second or control record of the subject's breathing was taken when respiration had again become uniform and normal. The operator then applied the pole-top method of resuscitation for from three to five minutes. A continuous record was taken on the smoked drum during this period. This

Table I. Records of Four Tests on Subject I, Pole-Top Method of Artificial Respiration

Date of Test (1940)	Operator Holding Relaxed Subject					Subject Receiving Artificial Respiration				
	10 Liters of Air					10 Liters of Air				
	Time to Move			Rate Resp.	C.C. Air	Time to Move			Rate Resp	C.C. Air
	Min.	Sec.	No. of Resp.	Per Min.	Per Resp.	Min.	Sec.	No. of Resp.	Per Min.	Per Resp.
2/1	1	20	19	14.6	526	1	00	11	11.0	909
2/6	1	30	19	14.6	526	0	55	13	14.1	769
2/16	1	25	21	14.8	476	1	5	9	8.3	1111
3/15	1	35	21	13.3	476	1	15	12	9.6	833
Av.	1	25		14.8	501	1	4		10.8	906

record was followed by a third control record while the operator still supported the subject. The operator then climbed down and the subject was again supported by the safety belt attached to the pipe support. In this position a final control record of normal breathing was taken.

A photograph of a subject on the pole with the operator in position and about to apply artificial respiration is shown in figure 1.

One of the records taken on the smoked drum is shown in figure 2. The record consists of three parts. The upper saw-toothed line is a record of the movement of the subject's chest. The increased movement during the period of artificial respiration may be seen clearly. Each dash in the middle line indicates that the subject has inhaled five liters of air. The increase in the amount of air moved during the application of artificial respiration is shown by the closer spacing of the vertical dashes. Each break in the bottom line records the passage of 30 seconds of time.

Three different individuals served as operators who gave artificial respiration during this investigation. Most of the work, however, fell to the lot of one experienced operator. The results obtained by different operators on the same subjects check remarkably well and give evidence of the uniformity of the work and of the passiveness of the subjects. Not only was the subject ignorant of the results obtained, but the operator was also in such a position as to prevent his seeing the record during the period of the application of artificial respiration.

Results

The results are given in tabular form. A small amount of resistance was introduced by the subject's breathing through the mask and the spirometer. Measurements of the variations in pressure in the mask were made with a water manometer. They were found to amount to less than one inch of water pressure. No corrections were made for these variations nor were corrections made for changes in barometric pressure or temperature of ambient air.

Variations Between Tests of Same Individual

As stated, two or more records were made on each individual by each of the three methods of artificial respiration studied. In table I the results for four separate records on subject I using the pole-top method are given. Two different operators were used on this subject.

Table II. Rate of Respiration Per Minute During Control and Artificial Respiration Periods

Subject	Age	Weight (Lbs)	Control: Std. Sch. Lying Prone	Control: Mod. Sch. Lying Prone	Control: Pole-Top Sitting on Belt	Artificial Respiration: Std. Schafer	Artificial Respiration: Mod. Schafer	Artificial Respiration: Pole-Top Method
I	60	155	13.2	10.8	14.3	9.1	11.5	10.8
II	54	175	15.3	14.3	16.8	12.0	11.0	10.8
III	42	134	14.5	11.1	16.9	13.7	9.6	7.0
IV	36	140	10.4	10.6	12.0	8.9	9.2	10.3
V	34	188	15.7	17.1	14.7	8.5	10.6	8.3
VI	24	125	13.7	13.6	14.3	8.6	11.4	7.5
VII	27	145	16.6	12.4	15.6	10.5	8.7	8.2
VIII	31	160	12.8	12.8	19.2	15.3	11.7	10.4
IX	27	211	12.0	12.0	12.0	12.3	12.0	10.9
X	20	148	9.0	9.0	8.1	8.1	6.6	8.1
XI	20	193	12.4	12.4	18.0	13.3	12.2	13.8
XII	49	130	11.2	11.2	9.4	5.3	6.5	4.7
XIII	28	140	15.3	15.3	15.1	14.5	13.3	10.9
XIV	38	160	12.8	12.8	13.7	11.6	10.1	12.9
XV	21	140	17.8	22.2	23.0	14.9	18.1	20.1
Av.			13.5	13.2	14.9	11.1	10.8	10.3

The data illustrate the differences found in repeated tests on the same individual.

Rates of Respiration

In table II are given the rates of respiration with the subject relaxed and lying prone in both the standard and modified Schafer methods and with the subject relaxed and sitting on the operator's belt in the pole-top method. In addition, the rate of breathing for all three methods of artificial respiration is also given. The age and weight of each subject is included in table II.

Lying prone in a relaxed posture the average rate of respiration was practically identical for the standard and modified Schafer methods. With the subjects sitting on the operator's belt the normal rate of respiration is somewhat higher as would be expected. The average rate of application of artificial respiration was substantially the same, namely, 11 times per minute, in both of the prone-pressure methods, and at a slightly less tempo, about 10 per minute, in the pole-top method.

Air Moved Per Respiration

Table III gives the cubic centimeters of air moved per inspiration for the subjects relaxed in the prone and sitting positions and for all three methods of artificial respiration studied. The air moved per respiration was naturally found to be the same for the two tests where the subjects were lying on the mattress. In the sitting position, it was slightly higher than for the prone position.

The artificial respiration results are given in the last three columns of table III. In the standard Schafer method the average was 868±51 cubic centimeters, and in the modified Schafer method 1,028 ±57 cubic centimeters. The pole-top method gave an average 1,363±85 cubic centimeters per inhalation. The

Table III. Cubic Centimeters of Air Moved Per Respiration

Subject	Control Period, Subject Relaxed: Lying Prone: Std. Sch.	Lying Prone: Mod. Sch.	Sitting on Belt: Pole-Top	Subject Receiving Artificial Respiration: Std. Sch.	Mod. Sch.	Pole-Top
I	463	410	501	635	839	906
II	528	505	509	729	972	1,485
III	576	576	526	611	1,340	1,340
IV	646	572	607	955	1,010	1,111
V	445	495	501	913	955	1,270
VI	403	467	451	769	646	1,429
VII	417	635	557	1,389	1,625	2,500
VIII	635	635	396	607	749	801
IX	667	667	714	625	714	1,000
X	662	662	742	1,111	1,270	1,667
XI	667	667	574	679	1,056	1,056
XII	555	555	742	1,500	1,715	2,250
XIII	488	466	500	572	628	837
XIV	487	487	530	850	932	1,459
XV	528	400	526	1,080	972	1,340
Av.	544	546	558	868	1,028	1,363

Behavior of Point Gaps at 60 Cycles

JEAN V. LEBACQZ
ASSOCIATE AIEE

VALUES of arc-over voltages for point gaps in air have often been considered rather inconsistent and difficult to reproduce with reasonable accuracy. Accordingly, a study was made to determine, first, if certain types of electrodes might give more consistent results than others and, if so, under what conditions, and, second, whether or not it would be possible to derive a formula which would take into account disturbing factors such as humidity. The results of this study are summarized in this paper, which, the author hopes, may be a small contribution toward a better understanding of arc-over phenomena.

Equipment

The gaps tested were set up vertically in the center of a specially built cylindrical chamber, 12 feet high and 12 feet in diameter, both the floor and ceiling of the chamber being made conducting in order to minimize the disturbances from surrounding objects on the field around the gap. One electrode was grounded, the other one being connected to the high-voltage side of a 350-kv 350-kva testing transformer. The air humidity in the chamber was controlled by the introduction of water vapor.

The electrodes studied are classified as follows:

Electrode Number	Description
1	$^3/_{16}$-inch round rod ended by a 15-degree cone
2	$^3/_{16}$-inch round rod ended by a section perpendicular to its axis
3	$^3/_{16}$-inch round rod ended by a 90-degree cone
4	$^3/_{16}$-inch round rod ended by a 120-degree cone
5	$^1/_4$-inch square rod ended by a section perpendicular to its axis
6	$^3/_{16}$-inch round rod ended by a hemispheres
7	Loud-tone phonograph needles

All the electrodes except the phonograph needles were made of brass.

To avoid erratic results due to oxidation and burning of the electrodes, an ultrahigh-speed circuit breaker was built and placed in the circuit. The arc current was actually interrupted by this breaker the first time it went through zero after the arc started—that is, in one quarter of a cycle or approximately $^4/_{1,800}$ second. This eliminated almost completely the burning of the points; and the pitting of the electrodes after more than 30 spark-overs with this breaker in the circuit was much less noticeable than that corresponding to one arc-over interrupted by a five- or six-cycle circuit breaker. It is the writer's belief that, without the use of this circuit breaker, the results herein described could not have been obtained. With a conventional type of breaker, it would have been necessary to change the points after each arc-over, a very lengthy and tedious task considering that, in order to derive the conclusions found, about 6,500 values of arc-over have been observed. A brief description of this high-speed breaker is given in appendix.

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The author is presenting in this paper a summary of the work he did at the H. J. Ryan high-voltage laboratory of Stanford University for his doctoral dissertation while he was a fellowship student of the Belgian-American Educational Foundation. He wishes to take this opportunity to express his appreciation to both Stanford University and the Belgian-American Educational Foundation for the facilities extended to him, and his sincere gratitude to Doctor J. S. Carroll for the aid and helpful suggestions given him.

plus-minus values given above are the probable error in the arithmetical mean and were calculated by the method of least squares.[7] A study of table III shows clearly that for every individual tested the amount of air moved per respiration in the pole-top method was equal or greater than that for either of the other two methods studied. The rate of respiration is, however, slightly less in the pole-top method than in the others. (See table II.)

It is also clear from the data that all three methods produce adequate ventilation of the lungs. In many of the subjects at the termination of artificial respiration there was a diminished concentration of carbon dioxide and an increased concentration of oxygen in the blood. The respiratory centers in the brain were not stimulated to activity and a brief period of apnea resulted. Soon normal breathing was resumed. This is clearly shown in the record in figure 2 where there is a brief pause in the chest movement following artificial respiration.

While in general, the modified Schafer method, where the hands are "snapped-off" the subject's back, moves more air than the standard prone-pressure method, it would, if continued for any length of time, tend to remove the skin from the subject's back.

Time to Move Ten Liters of Air

A very interesting method of studying the results is to compare the time required for the subject to breathe ten liters of air. When this was done, the average times are found to be as follows:

	Minutes	Seconds
Control period—lying prone	1	22
Control period—sitting on belt	1	12
Standard Schafer method	1	2
Modified Schafer method	0	54
Pole-top method	0	43

The above comparison shows clearly that all three methods of artificial respiration studied are efficient and that the actual volume of air moved by their use in a given time is comparable to the amount that the subject would breathe under normal conditions.

Conclusion

It is evident that the ventilation of the lungs obtained by the pole-top method is adequate and that the subject receives sufficient oxygen to satisfy his needs.

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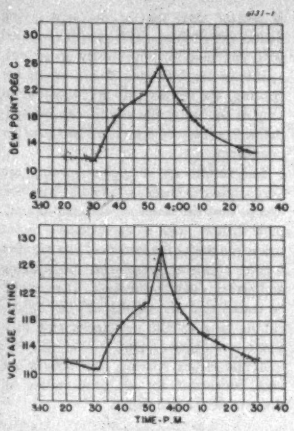


Figure 1. Variation of humidity and corresponding variation of arc-over voltage as a function of time

Gap number 3, spacing 12 inches, barometric pressure 29.9 inches of mercury

Apparatus

The voltage was measured directly from the voltmeter coil of the testing transformer. It must be noted that the purpose of this study was not to calibrate the point gaps, but to determine the relative effect of various factors on their arc-over voltages. For relative values only, the accuracy of these measurements may be considered as being better than 0.5 per cent.

The measurement of humidity required elaborate equipment. It was necessary to know, at all times, the value of absolute humidity inside the test chamber. To do this, a semiautomatic dew-point hygrometer was built according to the following principle:

Light emitted from a constant source was reflected onto a photoelectric cell by a highly polished nickel surface. If dew forms on the nickel surface, the amount of light reflected, and hence the current in the photoelectric cell, decreases. If the nickel surface is soldered on a wall of a small copper vessel, its temperature will be controllable by changing the proportions of a mixture of ice cold and hot water flowing through the vessel. This change can be achieved by the variation of current in the photoelectric cell, setting into action a suitable system of relays, motor, and valve in the hot-water circuit, to increase the temperature of the mixture as soon as dew is formed and to decrease it when dew has disappeared.

The temperature of the polished surface does not, however, respond immediately to the change of current in the photoelectric cell; to prevent any error that might occur from overshooting, a special device has been arranged to give exactly the time at which the dew forms or disappears on the polished surface. The temperature is measured by thermocouple; the polished nickel, being soldered on a sheet of copper, is used as the warm junction, the cold junction being immersed in melting ice. The resulting electromotive force is applied directly to a galvanometer, and readings are taken both when the dew forms and when it disappears, the average being taken as the true dew point. Tests made to determine the accuracy of this semiautomatic dew-point hygrometer showed that, under the most adverse conditions, the error in the dew-point temperature does not exceed 0.2 degree centigrade.

Tests and Procedure

The behavior of the following gaps has been studied:

Gap Number	Electrode Number	
	High Voltage	Ground
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
8	5	1

Spacings ranging from 6 to 30 inches were studied, except with gap number 7, for which the maximum spacing studied was 12 inches.

All the tests were made by varying the absolute humidity from approximately 10 to 25 millimeters of mercury. The air density was practically constant during the tests. It was not possible, however, to prevent a slight increase in temperature when the humidity was increased artificially by the introduction of water vapor in the test chamber. The resulting change in air density never amounted to more than two per cent.

Since the humidity inside the test chamber was varied continuously, the dew point was recorded as a function of time, while the value of arc-over voltage was observed every 30 seconds. The results are plotted as a function of time, and the average curves drawn (sample curves are given in figure 1). From these curves, the relation between the humidity and the voltage may be easily deduced. They also make it easy to determine under what conditions the readings are erratic, and also if they must be considered as low or high compared to the average.

Results

The results obtained will now be discussed by considering: first, the influence of the shape of the electrodes on the arc-over voltage; second, the combined influence of both the shape of the electrodes and the absolute humidity on the behavior of the gap; third, the effect of humidity for each type of electrode; and, finally, some of the other factors affecting the arc-over voltage.

1. Influence of the Shape of the Electrodes

Table I gives, in kilovolts effective, the arc-over voltages observed at a humidity of 15 millimeters of mercury for the different types of electrodes studied.

It is seen that the arc-over voltage for gap number 2 is 60 per cent greater at 18 inches and 35 per cent greater at 24 inches than that of any other gap. The arc-over could not be observed at 30 inches, but it is more than 20 per cent greater than that of the other gaps (over 360 kv). With that exception, all values observed at 18, 24, and 30 inches check within less than five per cent. Since no correction has been made for air density—the influence of which may amount to one or two per cent—and since, at the same air density, variations of a few per cent may occur for the same type of gap, it may be

Table I

Spacings (Inches) Gap Number	6	12	18	24	30
1	60.1	117.5	173	236.8	298.7
2	117.5	205	283	320	
3	61.5	119.2	181.5	239.5	302.5
4	66.3	119	177.5	244.3	297
5	85	136	179.6	235.8	296.5
6	72	120	174.2	237	298
7	61.2	116.3			
8	63.8	115	173.5	229.5	293.8

stated that, at these spacings, all the gaps studied in these tests give approximately the same arc-over voltage, except gap number 2.

The results at 12 inches spacing check within four per cent for all types of electrodes except two, and may thus also be said to be identical. The two exceptions are gap number 2, with an arc-over voltage 70 per cent higher, and gap number 5, which gives results approximately 15 per cent higher, than the others.

The arc-over voltage at six inches spacing is much more influenced by the shape of the electrodes; gaps numbers 1, 3, and 7 give the same value, and as the result for gap number 8 is only 4 per cent higher it may thus still be considered the same. The other results are higher; for gap number 4 by 12 per cent; for gap number 6 by 20 per cent; for gap number 5 by 40 per cent; and for gap number 2 by 95 per cent.

These results show that, as was expected, the smaller the spacing, the greater the influence of the shape of the electrodes.

2. Erratic Nature of Point Gaps

Gap number 2 will not be considered in the following discussion, because it gives erratic results at all spacings studied, and its arc-over voltage is always much higher than that of gaps formed by the other electrodes. The results obtained for the other gaps are shown in figure 2, *a* to *e*, and explained hereafter.

At six inches spacing, gap number 1 gives consistent results when the electrodes are clean. When they are burned, however, the readings are erratic and appreciably higher than those of clean points. The same effect has been observed for the phonograph needles, where a slight burning of the tip tends to make the results erratic and to increase the average arc-over value; however, at high humidity, the readings stay consistent even with the points slightly burned. Gap number 3, when clean, gives consistent results, while gaps 4, 5, and 6 are erratic; their arc-over voltage is greater than that of the gaps giving consistent results. The results obtained with gap number 8 are fairly consistent.

It may thus be stated that, at six inches spacing, the results will be consistent as long as the electrodes end in a single well-defined point, and erratic under the other conditions.

The results at 12 inches spacing are very similar to those obtained at 6 inches, except that the tendency for erratic readings with a none-too-well-defined point is less marked; for instance, gap number 4 gives consistent results at this spacing and erratic ones at 6 inches. It may also be stated that the results will be consistent as long as the electrodes end in a single well-defined point.

At 18 inches spacing, the results are very consistent for all gaps under all the conditions studied.

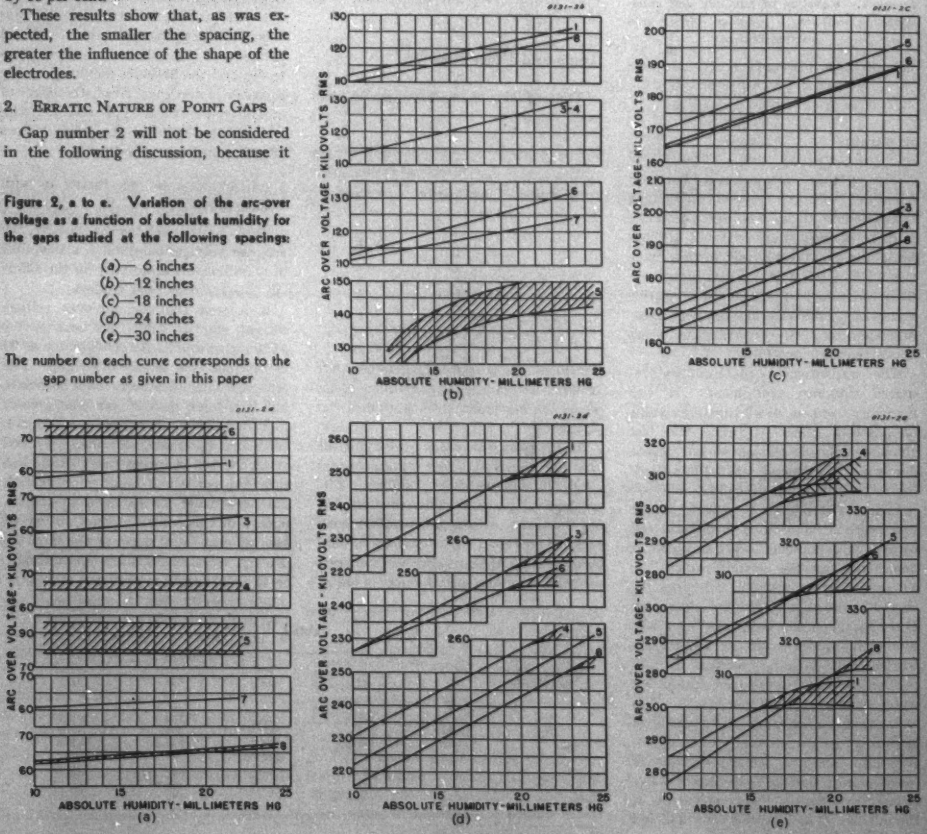


Figure 2, a to e. Variation of the arc-over voltage as a function of absolute humidity for the gaps studied at the following spacings:

(a)— 6 inches
(b)—12 inches
(c)—18 inches
(d)—24 inches
(e)—30 inches

The number on each curve corresponds to the gap number as given in this paper

Table II. Values of Arc-Over Voltage in RMS Kilovolts as a Function of Spacing and Absolute Humidity for the Gaps Studied

Gap Number	Humidity (Mm Hg)	Spacing (Inches) 6	12	18	24	30
1	10	58.1	112	164	223.3	284.7
	15	60.1	117.5	173	236.8	298.7
	20	62.1	122.8	182	250.2	(305.6)
2	10	116.6	200.5	277.5		
	15	117.5	205	283		
	20	118.6	(208)	288.5		
3	10	59.4	113	170.2	226	289.3
	15	61.5	119.2	181.5	239.5	302.5
	20	63.6	125.5	192.9	253	315.8
4	10	(66.3)	112.7	167.5	231.2	282.5
	15	(66.3)	119	177.5	244.3	297
	20	(66.3)	125.5	187.5	257.5	311.5
5	10	(85)	?	170.5	222	281.7
	15	(85)	(136)	179.6	235.8	296.5
	20	(85)	(144.5)	189	249.5	311.2
6	10	(72)	112.8	165.4	226	285
	15	(72)	120	174.2	237	298
	20	(72)	127	183	247.2	311
7	10	60.9*	111.4			
	15	62.1*	116.3			
	20	63.2*	121			
8	10	62	109.8	163.5	215.6	277.2
	15	63.8	115	173.5	229.5	293.8
	20	65.5	120.2	183.5	243.2	310.5

Note: Values in brackets have not been used for computing the relative influence of humidity.

* These values correspond to a spacing of $6^1/_{32}$ inches.

At 24 inches spacing, gap number 5 is the only one to give consistent results for all the conditions studied. With all the other electrodes, the results are consistent below a certain value of humidity, which will be referred to as "critical humidity". Above that value, they are always very erratic; the maximum readings fall on the extrapolated curve of voltage-humidity, but the average is notably decreased. Besides, it seems that, if the humidity is increased much farther, the voltage stays practically constant. The critical value of humidity appears to be approximately 20 millimeters of mercury for gaps numbers 1, 3, 4, and 6, and 23 millimeters of mercury for gap number 8.

The results at 30 inches spacing are entirely similar to those obtained at 24 inches; gap number 5 gives consistent results under all the conditions tested, while the others show a critical humidity, beyond which the average is decreased below the values expected from extrapolation. The critical value of humidity is approximately 17 millimeters of mercury for gaps numbers 1, 3, 4, and 6, and 20 millimeters of mercury for gap number 8.

The conclusion, therefore, is that, in order to obtain consistent results with the rod diameter used and at spacings between 6 and 18 inches, clean electrodes ending in a single well-defined point must be used. At spacings between 18 and 30 inches, however, a type of electrode offering several sharp points—such as a square rod ended by a plane section—should be used to obtain consistent results under all humidity conditions. Finally, a composite gap such as gap number 8 shows characteristics similar to those of gap number 1 at small spacings, while at large spacings, its behavior approaches that of gap number 5.

3. Influence of Humidity

For all the electrodes studied, the arc-over voltage increases linearly with the absolute humidity. There are, however, two exceptions. At six inches spacing, the arc-over voltage of the electrodes which give very erratic results does not seem to be influenced by humidity. At large spacings, when the humidity is greater than its critical value, the proportionality law holds true only if the maximum instead of the average readings are considered; and, for still higher values of humidity, the arc-over voltage seems to become independent of humidity.

Since the function of arc-over voltage versus humidity is linear, it was easy for comparison to compute the value of "relative influence of humidity". The author has called relative influence of humidity the percentage of increase in arc-over voltage corresponding to an increase of one millimeter of mercury of water-vapor pressure. It is thus given by:

$$I_h = 10\,\frac{V_{20} - V_{10}}{V_{15}} \text{ in per cent}$$

where V_{10}, V_{15}, and V_{20} are the arc-over voltages corresponding respectively to values of absolute humidity of 10, 15, and 20 millimeters of mercury. The values of I_h, obtained from tables II and III (see appendix), are plotted on figure 3, *a* and *b*.

It is seen immediately that the influence of humidity is far from being constant at all spacings. It attains a maximum of approximately 1.2 per cent per millimeter of mercury for spacings between 18 and 24 inches. On the other hand, the values observed may be considered as practically independent of the type of electrodes—with the exception of those observed with gap number 2.

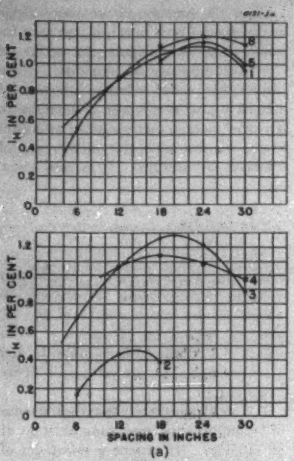
4. Other Factors Affecting the Arc-Over Voltage

Some observations made showed—as had already been observed—that the point gaps arc-over voltage increases with air density. However, no systematic study of that factor was made during these tests.

Some other factors as yet unknown have a decided influence on the point gaps arc-over voltages: differences as high as three per cent were observed from one day to another—sometimes even on the same day when the air of the test chamber had been disturbed—even if the temperature, barometric pressure, and humidity were exactly the same. It is supposed that these factors are either vapors or impurities such as dust parti-

Table III. Values of Relative Influence of Humidity I_h in Per Cent as a Function of Spacing for the Gaps Studied

Gap Number	Spacing (Inches) 6	12	18	24	30
1	0.67	0.92	1.04	1.14	0.94
2	0.17	0.44	0.39		
3	0.68	1.05	1.26	1.12	0.88
4		1.07	1.13	1.08	0.98
5			1.03	1.17	1.00
6		1.18	1.01	0.91	0.87
7	0.37	0.82			
8	0.55	0.90	1.15	1.20	1.13



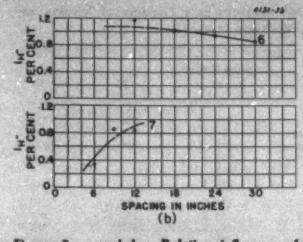


Figure 3, a and b. Relative influence of humidity I_h as a function of spacing for the gaps studied

The number on each curve corresponds to the gap number as given in this paper

cles in the air. This assumption is based on two observations made with gap number 1, at six inches spacing. The introduction of small quantities of ether vapor in the test chamber increased the arc-over voltage by approximately 17 per cent. A noticeable increase in voltage was also observed after introduction in the test chamber of vapors from moist wood. Lack of time unfortunately prevented any systematic research along these lines.

Conclusions

The results obtained from approximately 6,500 point gaps arc-overs under varying conditions may be summarized as follows:

1. The voltage at all spacings up to 30 inches increases linearly with an increase in absolute humidity.

2. The percentage of increase in voltage per millimeter of mercury increase in water vapor pressure is not constant at all spacings:

(a). It attains a maximum value of 1.2 per cent per millimeter of mercury for spacings between 18 and 24 inches;

(b). It is practically the same for all the electrodes studied in these tests.

3. At spacings of 18 inches or more, the arc-over voltage is practically the same for all the electrodes studied, provided they are ended by a finite number of points.

4. The readings are erratic at small spacings if the electrodes do not end in a single well-defined point or if that point becomes burned, thus offering a rough surface. The average is then greater than that obtained for a clean point.

5. Except for the electrodes number 5 ($^1/_4$-inch square rod ended by a section perpendicular to its axis) the readings are erratic at large spacings for high values of humidity. The average is then smaller than would be expected by extrapolation of the results obtained at lower humidity.

6. Under all the other conditions studied, the results were very consistent.

7. It is possible, by using two different types of electrodes, to obtain a gap partaking of the advantages of each electrode of which it is made.

8. Impurities or other vapors in the air affect the arc-over voltage.

Appendix

High-Speed Circuit Breaker

The ultrahigh-speed circuit breaker used in this experiment consisted primarily of a vertical plunger-type electromagnet, bearing three separate windings. The plunger had a displacement of approximately three-eighths inch, and acted on two sets of moving contacts of the breaker. It was rigidly connected to a pair of current-carrying contacts, and, during the last one-fourth inch of its travel, it opened a pair of arcing contacts. This ensured a total gap of one-half inch, quite sufficient to break a 2,000-volt circuit under oil.

The main winding carried the total primary current of the high-voltage transformer; the second winding created a flux exactly opposed to that produced by the exciting current of the transformer flowing in the first winding; and the third winding merely acted as a hold-open device.

The main winding was so designed that the pull on the plunger averaged about 80 times the weight of the plunger during the first one-fourth cycle of the arc-over current. At the end of this one-fourth cycle, the current went through zero, since it starts on the crest of the voltage wave and is practically in phase with the voltage. At the same time, the current carrying contacts had separated about $^3/_{16}$ inch, and the arcing contacts were beginning to move at such a velocity that the insulation between them and the stationary contacts was building up faster than the recovery voltage, thus preventing the arc from being established.

The purpose of the second winding was to prevent any pull on the plunger that might be caused by the exciting current, the value of which was approximately $^1/_{30}$ of the arc-over current. Besides, it created the only flux keeping the contacts open between the interruption of the arc-over current and the establishment of the current in the third winding.

The third winding was necessary because the contacts were not designed to close the circuit and had to be kept open until the generator voltage was brought down to zero, thus preventing any rush of exciting current while the contacts were closing. A suitable system of relays was set up so that after the breaker had opened the circuit, current started flowing in the third winding, and by manual operation of a single switch, the generator voltage was brought down to zero, the breaker closed, and the transformer voltage built up to about 90 per cent of the expected arc-over value.

The operation of this breaker proved to be very satisfactory, since practically no arcing was visible, even when interrupting currents of 300 amperes rms at 2,000 volts.

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The Effect of Overexciting Transformers on System Voltage Wave Shapes and Power Factor

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IT is well known that the voltage and current wave shapes of transmission and distribution circuits are distorted more or less from a true fundamental-frequency sinusoid. Several years ago extensive tests were conducted, measuring the wave shapes for different types and voltages of circuits.[1] There were however no definite conclusions drawn concerning the origin or improvement of these wave distortions.

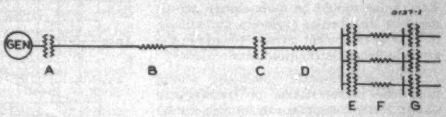
Measurements by the authors of harmonics on various systems in the country, as well as those measurements referred to, show in general that the harmonic voltages increase in magnitude as the measurements are made farther and farther from the generating stations. This indicates that probably transformer exciting currents have more effect on system wave shapes than is usually given credit.

The nontriple odd-harmonic frequency components of exciting currents of all the transformers in a system are supplied by generators, load circuits, or system capacitances. The ohmic values of the load and capacitive circuit impedances are usually many times those of the circuits which include the generating points or similar large rotating machines. Hence, practically all of the nontriple-frequency components of exciting current for transformers can be said to be supplied by the generators.

With this thought in mind one can appreciate that transformers in outlying districts may have to draw their exciting current through a great deal of impedance. Current going through impedance naturally produces voltages in accordance with Ohm's law so it can well be expected that under the proper conditions the harmonic content of these exciting currents could have a measurable effect on system wave shapes. Further, it is well known that in general, due to inadequate regulating equipment, and other reasons, certain transformers are overexcited in order to deliver the desired voltages at the load. It is, however, not so well recognized that this overexcitation greatly magnifies these system harmonics and reduces the system power factor. This reduction in power factor results in less boost in voltage than is expected with the final result being *excessive* overexcitation in certain areas, with the attendant decreased power factor, increased losses, and increased harmonic content of the voltage and current waves. It was the desire to determine more or less quantitatively what effect this overexcitation of transformers might have on system wave shape and power factor that prompted this study.

Figure 1. Diagram of the hypothetical system analyzed

Refer to table I for explanation of symbols



Experience and measurements show in general that the third-harmonic voltages and currents are relatively small. This is because nearly all three-phase transformer banks have one winding connected delta, which permits the triple-frequency currents to circulate thus preventing them from flowing beyond the first delta winding. The only triple-frequency voltage then that gets out on the system is that which represents the impedance drop in the lines to the first delta and the delta windings themselves of the third harmonic currents. Experience shows that the fifth harmonic is generally the largest single harmonic component in the current and voltage waves. It is appreciated that the magnitude of various harmonics varies considerably in any given system, but in general it has been found that the fifth is the largest component. Admittedly, in isolated cases motors or generators generate higher frequencies known as "slot ripples", which may need special attention, but this phase of the subject is not studied.

In order, therefore, to assign definite objectives to the problem, it was decided to study the effect of transformer overexcitation in a sample system on the fifth-harmonic voltage and power factor and determine what practical methods were available for improving these conditions if and when they required it.

General Method of Attack

The hypothetical system represented by figure 1 was chosen for study. Average typical circuit constants and transformer ratings were assumed as listed in table I. This circuit, with each transformer represented by its equivalent with a harmonic generator in its magnetizing branch for supplying harmonic current (refer to figure 2 and appendix) was set up on the a-c network analyzer. With this arrangement, the circuit constants, the magnitude of harmonic current flow for different values of excitation, and the ratio between substation and distribution transformer capacity could be readily varied.

With a predetermined excitation on the transformers, the magnitude of the fifth-harmonic current required was made to flow by adjusting the voltage of the harmonic generator in each transformer circuit. With these adjustments made, the fifth-harmonic voltage was then read at any desired point in the system. This procedure was carried out for normal and 110 per cent excitation on all transformers.

This type of test assumes a pure sine wave of fundamental voltage is applied to each transformer, which is not true in the strictest sense of the word since the reactance from the voltage source to each transformer results in small harmonic voltages being applied instead of a pure sine wave. This error is small for the value of voltages encountered hence the effect is neglected.

Conclusions

1. A small negligible value of fifth-harmonic voltage can be expected to appear in transmission and distribution circuits as a

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1. For all numbered references, see list at end of paper.

result of the flow of fifth-harmonic components of exciting currents required by normally excited transformers.

2. This fifth-harmonic voltage is more than doubled when the excitation on the majority of the transformers in a system is increased ten per cent.

3. The over-all system power factor can be materially reduced by exciting currents resulting from *excessive* overexcitation of the majority of the transformers.

4. Since the advantages of operating at the present established levels of meter-box voltages cannot be denied, distribution systems utilizing a large proportion of the older designs of distribution transformers requires more careful operation and regulation in order to not excessively overexcite the transformers.

5. The use of capacitors and reactors in series for the dual pupose of power-factor and wave-form improvement provides a simple, effective, and economically sound method of coping with these two problems presented by the overexcitation of transformers.

6. The replacement of obsolete distribution transformers with up-to-date built-for-the-service equipment would reduce these harmonic voltages, excessive exciting currents and losses, caused by overexcitation. This point should be more closely scrutinized by distribution engineers, particularly in view of the recent advances made in the art of building distribution transformers.[3]

7. The objectionable conditions arising from the overexcitation of transformers should further encourage the movement attempting to standardize circuit and appliance voltages so that further increases in transformer voltages will be unnecessary.

Transformer and Circuit Data of System in Figure 1

The system analyzed and represented by figure 1, does not necessarily represent any particular system in existence but it does represent in substance the equivalent amount of transformers and lines that might be used in transmitting and distributing a given block of power.

The power transformers in the line are assumed to be of 100 per cent capacity while each of the three step-down substation transformers are taken as 50 per cent capacity. Diversity in feeder loads usually requires at least this ratio of capacities. The complete circuit data including ratings and reactances of the various lines and transformers, and the per cent exciting currents used are listed in table I. For purposes of this study, it is assumed that an average normal density of 70 kilolines per square inch is representative for the distribution transformers and a density of 85 kilolines for the power transformers.

In figure 3 are plotted the data of a harmonic analysis of the exciting current of a representative iron that might be used for transformers. Thus, for the different values of excitation studied the per cent harmonic content of the exciting current can be obtained. It should be noted that these data give the per cent harmonic content of the total exciting current. Since it is the *total* amperes of harmonic current flowing that determines the voltage, these percentage values must be co-ordinated with the actual magnitudes, of exciting current. A certain transformer under an overvoltage condition might require 10 per cent total exciting current having 10 per cent fifth harmonic while another could require 4 per cent total current but having 20 per cent fifth. Thus the one having a *less percentage* of fifth may actually have *more amperes* of fifth harmonic.

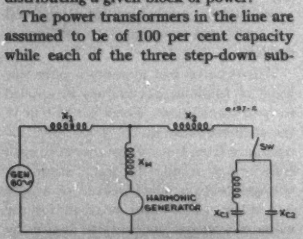

Figure 2. Diagram of equivalent transformer circuit with harmonic generator in the magnetizing branch for supplying the required harmonic currents. The switch connects a series reactor-capacitor combination for improving wave form and power factor—refer appendix

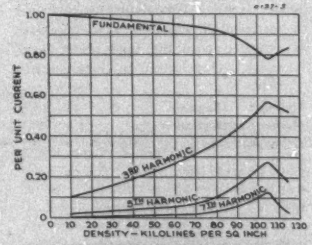

Figure 3. Harmonic analysis of the exciting current of a representative sample of iron that might be used for transformers

Data plotted as per unit of total exciting current against density

Normal Excitation on All Transformers

This study involved the determination of the fifth-harmonic voltages in the hypothetical system laid out in figure 1 for normal excitation on all transformers. This is indeed somewhat of a hypothetical condition, since never would a system be found that had normal voltage applied to all transformers. However it does have the academic value of showing to what extent normal-excitation exciting currents would generate harmonic voltages in such a system.

The voltages that the prescribed values of harmonic current caused to appear in the test system are shown plotted by the solid lines in figure 4. Curve *A* represents the conditions when the ratio of distribution to substation capacity is unity. Here it is seen that the fifth-harmonic voltage gradually rises from zero at the generator to approximately 0.02 per unit in the distribution area. The solid curves labeled *B* and *C* show the voltages when the distribution-transformer capacity ratio was increased to 2 and 3 respectively. Here it is seen that the harmonic voltage increases slightly for these two conditions. These figures are representative of the lower values of fifth-harmonic voltages measured in actual systems.

1.1 Per Unit Excitation on All Transformers

The next consideration was that of determining the fifth-harmonic voltages when all the system transformers were overexcited ten per cent. Again, the reader is cautioned that this does not necessarily represent a practical case, but it does show, when compared with the results of the previous case how the harmonic voltages can be expected to increase when the transformers are operated above their normal densities.

The exciting currents for this condition of excitation, for the two types of transformers are listed in table I.

Cases *A*, *B*, and *C* were analyzed for this condition just as they were for normal excitation. The dashed curves in figure 4 show the fifth-harmonic voltages measured for the three different values of distribution transformer capacity. These data show that the harmonic voltages are more than doubled over the values obtained for the condition of normal excitations on all transformers.

In an actual system, these harmonic voltages are usually amplified more or less by the transmission line and transformer capacitances, so it is not uncommon to find voltages much higher than those shown in figure 4. Also, the magnetizing current required by induction motors and other "iron core" loads have their effect in increasing these voltages. In fact all loads with nonlinear impedance characteristics contribute to this phenomenon.

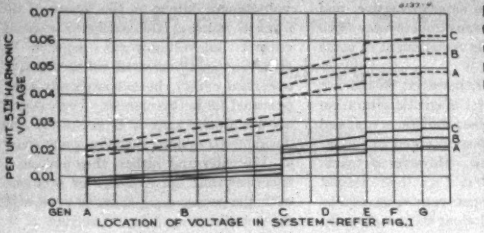

Figure 4. Magnitude of fifth harmonic voltage appearing in the hypothetical system studied

Solid curves—Normal excitation on all transformers
Dashed curves—1.1 per unit excitation on all transformers

The authors have studied test data taken on two systems that exhibited unusually high fifth-harmonic voltages. In these tests it was found that a general lowering of the voltage levels by approximately 10 per cent, resulted in a decrease of 50 per cent in the fifth-harmonic voltages.

On another occasion, severe overcurrents were being experienced due to the circuit being in *partial* resonance with capacitance. It was found that a decrease of only 4 per cent in the voltage feeding the affected area reduced the harmonic condition sufficiently to cure the difficulty.

Reduction of Harmonic Voltages Arising From Exciting Currents

In certain areas the application of shunt capacitors has been somewhat impeded due to these harmonic voltages. Resonance has occurred on occasion resulting in excessive fuse blowing. Also an occasional case of low-frequency induction in communication circuits has been experienced. Almost without exception these cases have been controlled by the fifth-harmonic or 300-cycle component. Therefore it is believed that if a method of reducing this component to a negligible amount was realized, the broad problem could be considered solved.

Use of Capacitors. Since capacitors have more or less exposed this harmonic condition in modern distribution circuits during the last few years, it seems paradoxical that they could be used to suppress these harmonic voltages. Such a method however is available and attention is directed to it in this paper since it is believed to be not very well known in this country. It has however been used successfully for several years in Japan[3] in the larger capacitor installations.

The scheme consists of putting a reactor in series with a group of capacitors. This reactor is proportioned in respect to the capacitors, so that the combination is in or near resonance with the fifth harmonic. The fifth-harmonic voltage is then effectively short-circuited at the point of application with the improvised resonant shunt. In fact it can be shown that it is reduced to a negligible amount in the surrounding area for a considerable radius. The amount of harmonic current that flows into this "harmonic short circuit" is equal to the voltage at that point before the equipment was applied divided by the system impedance viewed from that point. In general this current will not be so much since the harmonic voltage isn't large to begin with and further the system reactance is large, being increased by the order of the harmonic. It is interesting to reflect on the possibilities of this scheme when carried to a limit. If a sufficient number of these "harmonic short circuits" or resonant shunts were applied to a system, practically all of the fifth-harmonic current could be made to flow in short localized paths from the transformers to the shunts, thus practically eliminating the harmonic voltages from appearing, as described in the body of the paper.

A very important point to remember in this respect is that the normal, 60-cycle power-factor improvement afforded by the capacitors is not reduced by this series reactor. Since approximately a four per cent reactor is required for this application, the 60-cycle voltage on the capacitors is raised by this amount and the net available corrective kilovolt-amperes to the system is likewise increased by four per cent. If it is desirable from other considerations to practically eliminate the flow of harmonic current instead of the harmonic voltage, the reactor can be so proportioned to make a harmonic wave trap (equation 5 in appendix) out of the capacitor bank, and as before the normal 60-cycle correction afforded by the capacitors is increased by the reactor. Thus it is seen that power-factor and waveform improvements can be obtained simultaneously by a single master stroke.

Reduction of Transformer Excitations

Reducing excessive overexcitations and providing the proper regulating equipment for voltage control would, of course, be in order where it could be justified. No doubt there are many transmission and substation transformers that could be operated at much lower densities if the distribution circuits were properly regulated.

The distribution transformers however, in general, cannot have their voltages reduced without accepting certain losses in revenue and a reduction in the quality of service rendered. As described in more detail below under power factor, it is well known that in the last several years the transformer secondary voltages have been creeping up from 110 to 125 volts and even higher. Obviously many older-type transformers originally designed for 110 volts are now operating 10 per cent and even 15 per cent overexcited. In view of these trends, it is believed that a policy of more closely scrutinizing the replacement of obsolete equipment with up-to-date designed-for-the-service apparatus would prove a sound investment.

Curves ..... A ... B ... C
Ratio of Distribution Substation Capacity ..... 1 ... 2 ... 3

Table I

Equipment Identification Refer Figure 1	Type of Equipment	Per Unit Rating	Per Unit Reactance on Own Base	Per Unit Exciting Current on Own Base: Normal Excitation	Per Unit Exciting Current on Own Base: 1.1 Per Unit Excitation
Generator	Sine-wave voltage source	Infinite	0		
A	Transformer—step up	1.0	0.08	0.045	0.08
B	High-voltage transmission line	1.0	0.05		
C	Transformer—step down	1.0	0.08	0.045	0.08
D	Medium voltage distribution	1.0	0.05		
E	Three substation transformers	0.5 ea.	0.05 ea.	0.04	0.07
F	Three lines—four-kv feeders	0.5 ea.	0.05 ea.		
G	Transformer equivalent of total connected distribution transformers, Case *A*	0.5	0.025	0.02	0.03
	Case *B*	1.0	0.025	0.02	0.03
	Case *C*	1.5	0.025	0.02	0.03

Cases *A*, *B*, and *C* differ only in the ratio of connected distribution to substation transformer capacity, of which the ratios are 1, 2, and 3, respectively.

System Power Factor and Overexcitation of Transformers

The past several years has seen in general a marked decrease in over-all system power factor. The deleterious effects of poor power factors coupled with increased loads upon system capacity and voltage are well known. The answer to the questions inquiring into the cause of this decrease in power factor has generally been "motorized appliances, air conditioning, gaseous-tube lighting, etc." These factors beyond a doubt have had their effect, but it is interesting to speculate on the effect of transformer magnetizing currents, especially when the transformers are overexcited.

Not so long ago it was the practice to serve a customer with 110 volts, or its equivalent at a higher level. Later the standard was considered to be 115, so taps were changed and general levels raised to accommodate this change in philosophy. During the last few years this meter-box voltage has risen to 120 which represents approximately a ten per cent increase over the original 110. In fact in many places it is necessary to hold 125 volts or even higher at the transformer in order that the load be served at rated voltage. During the evolution of this practice of gradually raising the voltage, new transformers designed for the voltage were of course being added to accommodate load growth, but, most of the older equipment obviously remained on the system. Thousands of kilovolt-amperes of transformers on most systems today that were built to operate at a normal density corresponding to 110 or 115 volts, are actually being operated at or above 120 volts. Transformers in general can stand this duty because they are designed for it, but obviously they must draw larger magnetizing currents to accommodate the increased flux requirements.

The effect on the magnitude of the total exciting current required by all the transformers in the circuit of figure 1 due to overexciting the transformers ten per cent is clearly seen by the figures in table II. Here it is seen that the exciting-current requirements are practically doubled, for the overexcited condition. For the case at hand, reactive kilovolt-amperes approximating 40 per cent of the system rating may be required merely to excite the transformers. These figures may of course be off a little quantitatively, but they are believed to be sufficiently accurate qualitatively to show that system power factor can be materially reduced by operating transformers above their normal densities. It is well known that many times a generator must be kept on the line merely to supply reactive, and the overexcited transformers may well be the cause of the requirement in some cases.

The transformer, however, should not be indicted for this. Magnetic saturation is a fundamental characteristic of iron and must be more or less accepted in the interests of economy. However if transformers were operated at their normal densities and proper regulating equipment were applied along with a properly designed distribution system, these exigencies would not arise. Admittedly this is a Utopia impossible to attain, but it is believed that with these facts known and understood, more attention to the problem can be intelligently and profitably applied. Magnetic saturation and magnetizing reactive kilovolt-amperes is something with which the engineer must live—hence it behooves him to treat it with respect and design his systems accordingly. It is believed that the replacement of lots of these older, overexcited distribution transformers with up-to-date designs and/or the use of appropriate regulating equipment could be justified from the standpoint of decreased losses and decreased magnetizing currents alone. One should not conclude from this discussion that power-factor improvement be attained by reducing voltages, but the over-all condition can be greatly improved by properly regulating the voltage. In this respect the authors are acquainted with one distribution system in which voltage regulators were systematically applied and much to the surprise of the engineer, the power factor coincidentally was improved from 70 to 85 per cent.

Reference to the preceding section on reduction of harmonic voltages should be made for further discussion of reactive control. In this section the use of capacitors is described for improving wave form distortions due to saturation and at the same time provide leading kilovolt-amperes for power-factor improvement. It is interesting at this point to note that since shunt capacitors increase their kilovolt-ampere output as the square of the applied voltage, the increased exciting current kilovolt-amperes required by transformers at increased voltages can, to a certain extent, be automatically compensated for in this manner. These points are mentioned since it is profitable and desirable to operate distribution systems at 120 volts and higher, thus making it necessary that the engineer be provided with the proper equipment to cope with the conditions resulting therefrom.

Table II

Total Per Unit Exciting Current Required by Transformers in Circuit of Figure 1 for Various Excitations and Ratios of Distribution to Substation Transformer Capacity. Kilovolt-Ampere Base = 1.0

Capacity ratio	1/1	2/1	3/1
Normal excitation	0.18	0.21	0.24
1.1 per unit excitation	0.31	0.35	0.40

Appendix. Use of an Equivalent Circuit for Determining Flow of Harmonic Magnetizing Currents

Consider the circuit shown in figure 2 which is the equivalent diagram of a transformer connected to a pure sine-wave voltage source with a harmonic generator in the magnetizing branch for furnishing the harmonic magnetizing currents. The circuit connected by the switch represents a set of capacitors, x_{c1}, in series with a reactor x_r and a set of capacitors, x_{c2}, with no reactor.

Consider the switch open, and the transformer excited from the pure 60-cycle source. Since there is magnetic saturation in the x_m branch, certain harmonic currents will flow and these can be represented as being driven through the system by a harmonic generator located in the x_m branch. Then letting

i_n = harmonic current
x_1 = 60-cycle reactance of system up to transformer plus transformer primary reactance
x_2 = same on secondary side
n = order of harmonic

the harmonic voltage at the switch can be written as

$$e_n = i_n n x_1 \tag{1}$$

This reasoning assumes that the magnitude of i_n is determined solely by the applied 60-cycle excitation sine wave of voltage and neglects the infinitesimal amount that flows due to the appearance of a small harmonic voltage at the transformer terminals.

Assume further that the reactor x_r and the capacitor x_{c1} are proportioned so that

$$n x_r = x_{c1}/n \tag{2}$$

then the harmonic current meets zero impedance when the switch is closed.

Closing the switch results in the flow of i_n' through the switch of the magnitude

$$i_n' = i_n \frac{n x_1}{n(x_1 + x_2)} \tag{3}$$

and substituting equation 1

$$i_n' = \frac{e_n}{n(x_1 + x_2)} \tag{4}$$

Thus, to determine the readjustment of the flow of the harmonic current due to a resonant shunt or a "harmonic short circuit" it is merely necessary to divide the voltage at the point of application by the

Testing of Elevator Buffers by Electrical Means

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THE PURPOSE of an elevator buffer is to stop the elevator in event it reaches the bottom of its hoistway out of control. To prevent injury to its occupants, the rate of stopping must not exceed $2^1/_2$ times gravity or about 80 feet per second per second for more than $^1/_{25}$ second. The tests on a buffer should be such that the velocity at which the elevator strikes the buffer and the rate of deceleration at every point in the piston stroke may be determined. If the buffer contains oil, it is important for the designer to know also the oil pressure at every point in the stroke.

Methods Formerly Used

The test method found most satisfactory up to this time employs a platen, driven directly from the buffer piston or by the elevator, on which a tuning-fork-driven stylus records the distance traveled by the platen during successive cycles of the fork vibrations. From this record the velocity and deceleration are calculated. A modified steam-engine type of pressure indicator operates another stylus on the same platen to record the varying oil pressure.

In methods previously used, the tuning fork vibrates with constant frequency while the platen velocity varies with that of the car. This arrangement produces a record on which the highest velocity of fall produces the fewest cycles per inch on the record. With the electrical method described, the highest velocity of fall is recorded with the greatest number of cycles per inch of record and the accuracy of the calculations of retardation are best therefore when the velocity of fall is highest. Inasmuch as dangerous deceleration rates are more likely to occur early rather than late in the stroke of a buffer reasonably well designed, it is better to achieve accuracy of measurement at the higher rather than at the lower velocities.

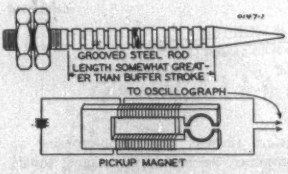

Figure 1. Pickup magnet and grooved iron inductor rod

Determination of Velocity and Deceleration

To determine the striking velocity of the elevator car, a magnetic pickup coil and grooved iron rod shown in figure 1, is used. The rod is mounted vertically on the car, attached by its upper end so that as it falls with the car it passes through the bore of the pickup magnet which is mounted on one of the guide rails. The magnet has an exciting winding of about 200 turns of number 18 magnet wire and also a secondary coil of about the same number of turns which is connected to a high-sensitivity galvanometer element of an oscillograph. As the rod drops through the bore of the pickup magnet, the changes in permeance of its magnetic circuit, caused by the grooves in the rod, vary the magnetic flux and induce in the secondary coil an alternating voltage, which is recorded by the oscillograph. One six-volt storage battery serves to excite the pickup magnet. A similar rod and pickup coil may also be used on the buffer piston itself if the performance of the piston must be known.

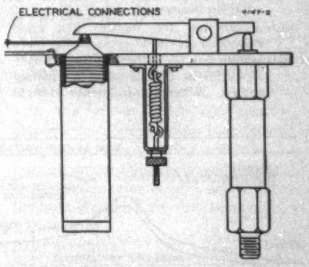

Figure 2. Carbon-pile oil-pressure gauge

A 60-cycle voltage wave on the same oscillogram as the varying-frequency alternating voltages of the pickup coils is of convenience in timing.

In calculating the velocity of the car at any point in its fall the following formula may be used:

$$V = \frac{5NL \times m_{60}}{m_r}$$

in which

V = velocity of fall in feet per second
N = number of cycles scaled on pickup record on oscillogram

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driving point impedance of the circuit viewed from that point. This fundamental principle has been used for years by engineers in making short-circuit calculations. It can be shown, within the assumptions, that this method of calculating the flow of short-circuited harmonic current in a complicated network, is correct. The demonstration above for a simple circuit is given in the interests of clarity.

It is interesting to note that if x_2 is proportioned so that

$$nx_2 = x_{c1}/n + x_{c2}/n \qquad (5)$$

a wave trap is formed by the network, which presents infinite (neglecting losses) impedance to the harmonic thus preventing the flow of harmonic current.

Either of these reactor schemes can be used in capacitor applications depending upon the objective. The condition imposed by equation 2 reduces the line harmonic voltage to zero whereas the conditions represented by equation 5 reduces the line harmonic current to zero.

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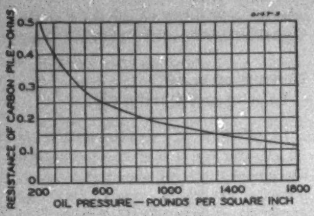

Figure 3. Typical carbon-pile pressure calibration curve

L = distance in inches between centers of adjacent grooves on rod

m_{60} = millimeters (or inches) per cycle measured on the 60-cycle timing wave

m_1 = millimeters (or inches) measured over N cycles at chosen point on pickup record. When the frequency is high, three or four cycles should be used. When the frequency is low, two cycles are sufficient.

To obtain the curve of deceleration versus inches of stroke it is necessary to plot a curve of velocity versus time from figure 5. The slope of this curve at any point is then the rate of change of velocity from which the curve of deceleration of figure 5 is plotted.

Measurement of Oil Pressure

The oil-pressure gauge consists of an oil-pressure cylinder and a carbon pile mounted together with a rocking beam connecting them as in figure 2. The carbon pile consists of 42 carbon disks each of which is $^1/_8$ inch thick and $1^1/_2$ inches in diameter. The disks were ground to a true surface on each side as far as possible. The disk pile is enclosed in a paper tube and inserted in a brass tube shown in figure 2. The rocking beam by which the pressure at the piston is transmitted to the carbon pile has a lever arm ratio of $1^1/_2$ inches to $4^1/_2$ inches. Because the long end of the beam moves only $^1/_{16}$ inch with the greatest oil pressure encountered, inertia effects are reduced to a satisfactory minimum.

The carbon pile is calibrated in resistance versus pressure. The current through the carbon pile and the voltage across it are both recorded on the oscillograph film so that the resistance may be calculated and the pressure determined for any point in the piston stroke. A calibration curve is shown in figure 3. Figure 4 shows a sketch of a typical oscillogram. Figure 5 shows the final curves of performance of the buffer.

Difficulties to Be Avoided

To obtain sufficient voltage in the pickup magnet coil to operate the oscillograph element without interposing an amplifier, the hole in the magnet should not exceed three-fourths inch in diameter when a five-eighths-inch grooved rod is used. Grooves one-eighth inch long, one-eighth inch deep and spaced three eighths inch apart were found quite satisfactory.

If there is no guide provided for the suspended rod, the impact of the car on the buffer piston may cause the rod to deflect and strike the pickup magnet instead of its hole. A long brass point fitted to the rod attached to the car proved helpful in guiding that rod through the pickup magnet in its fall. A fiber bushing in the pickup magnet hold (not shown in figure 1) was found helpful in guiding the rod. It was also found advisable to mount the magnet so that it was free to move laterally to follow any swinging of the rod.

In comparison with electric strain gauges recently developed the carbon pile has the advantage of requiring no amplifier or source of high-frequency voltage for oscillographic recording.

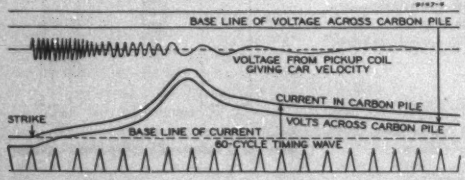
BASE LINE OF VOLTAGE ACROSS CARBON PILE
VOLTAGE FROM PICKUP COIL GIVING CAR VELOCITY
CURRENT IN CARBON PILE
STRIKE
VOLTS ACROSS CARBON PILE
BASE LINE OF CURRENT
60-CYCLE TIMING WAVE

Figure 4. Typical oscillogram from which the performance of the buffer is calculated

Summary

The curves of figure 5 are typical of those obtainable by the electrical apparatus described. Inasmuch as the oil-pressure indicator was connected to the bottom of the buffer cylinder, there was a short time interval between the instant of maximum pressure as shown on the pressure gauge and the maximum deceleration. This time interval is that required for the high-pressure wave to travel through the oil from the piston to the gauge. This difference in time demonstrates the elasticity of the light transformer oil used.

The accuracy of this method is satisfactory for all existing test codes.

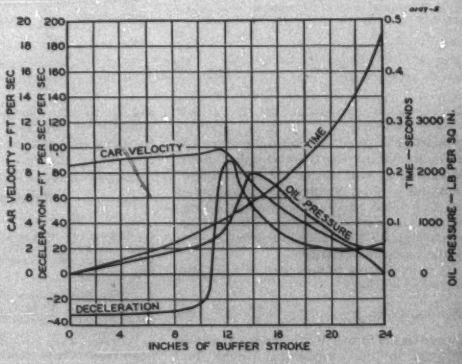

Figure 5. Typical performance curves of a buffer with poor workmanship or of poor design

Single-Phase Induction-Motor Performance Calculation

F. S. HIMEBROOK
MEMBER AIEE

IN the manufacture of electrical machines it is always desirable to calculate the performance of a machine before its construction to determine whether or not it will meet the specifications. The usual methods of predetermining performance involve the use of either a circle diagram or an equivalent circuit and since either of these methods involves considerable work there are always possibilities that errors may be introduced by slight mistakes in construction, measuring, etc. It was believed that if a method could be developed by which the quantities necessary for performance calculation could be given in the form of a set of curves considerable time might be saved provided that the accuracy so obtained was of the same degree as that given by other methods.

This paper describes the development of a method which may be used to plot, as families of curves, the quantities necessary for the performance calculation of single-phase induction motors. Consideration is first given to a circle diagram which is known to give accurate results when used to calculate the performance of motors of this type. It is then shown that all of the quantities involved in the calculation of performance are dependent upon certain ratios of the fundamental motor constants and not upon the absolute values of the constants. This means that it is not necessary to draw a new circle diagram for each motor and any diagram may be used in any number of cases as long as the fundamental relations are held constant. Thus if a number of diagrams are made for different ratios of motor constants the data required for performance determination may be evaluated and plotted in the form of curves which may be used to take the place of the circle diagrams. Such curves are at least as accurate as the diagrams they replace because slight errors in reading values become apparent when plotted and tend to be either minimized or averaged out.

Besides the motor characteristics in the usual operating range it is always desirable to know the value of the maximum torque. It was found that the information required for the calculation of the maximum torque might be determined by making use of the diagrams previously described and a method of plotting the necessary quantities in the form of curves is given.

Extension of the methods given for the calculation of the performance of polyphase motors is shown to be possible and is discussed briefly.

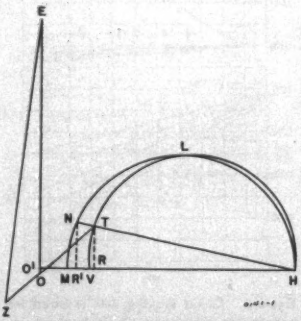

Figure 1. Circle diagram used in determining performance of single-phase induction motors

The Circle Diagram

The circle diagram used (figure 1) is the one given by Branson[1] in his paper which explains the operation of the single-phase motor by the cross-field theory. The methods of constructing this diagram and of using it are included in appendices I and II.

By reference to appendix I it will be seen that since $O'H$ is a constant and since $O'M$ is a variable dependent only upon K_r (defined in appendix I), that the value of MH and the semicircle $MNLH$ are also functions of only K_r. Thus, for any particular value of K_r this part of the diagram is fixed.

In a like manner, the value of MV is determined by the value of K_r and point V located accordingly. The value of LH is dependent upon both K_r and the ratio r_2/X but for any particular values of these two quantities the point L is definitely located. Because points V, L, and H are all located and because all three points must lie on the circumference of one circle the center of this circle is located at the intersection of the perpendicular bisectors of lines VL and LH. After the center has been located arc VLH may be swung.

Actually the line OO' is not constant, as assumed in appendix I, but varies with the motor under consideration. However the assumed value is sufficiently close to the average value calculated for normal motors that the error introduced by this assumption is very slight. Having located point O the directions of lines OT are defined.

By definition

$$OZ = (S_1 r_1 / S_s) \times OT \qquad (1)$$

and by substituting equivalent values for S_1 and S_s we may change this to the form

$$OZ = \frac{(E/10X)}{(E/OE)} \times r_1 \times OT = \frac{(OE = 10)}{10X} \times r_1 \times OT = \frac{r_1}{X} \times OT \qquad (2)$$

giving a solution for the length OZ which is a direct function of r_1/X.

Thus it is seen that the entire diagram is dependent only upon K_r, r_2/X and r_1/X and that the performance of all motors having the same values for these quantities will be identical. Since this is true it is evident that with the use of only a relatively small number of diagrams it is possible to determine the performance of a wide variety of motors. We may also proceed one step farther and plot the values of OT, MT, etc., in the form of curves and so have all of the information required for performance calculation in a convenient form. In carrying out this work for a given value of K_r it will be found convenient to plot the values of OT, MT, etc., against the length of MN since this value remains constant for a given value of K_r regardless of the ratios r_1/X and r_2/X.

This method of plotting the curves may be seen by reference to figures 2 and 3. In some cases all of the values for the

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The writer wishes to thank The Hoover Company for permission to publish this paper, the material for which was developed while a member of their engineering department.

1. For all numbered references, see list at end of paper.

ranges of r_s/X considered do not differ appreciably and so only one value has been shown. For example the values of TR as shown all lie within about 0.01 inch of the value shown and since errors in measurement might have been at least ±0.01 inch it was not believed necessary to attempt to show any more than one curve.

In calculating the performance the procedure followed is that outlined in appendix II.

Performance Calculation Using Curves

In the final analysis the utility of a method lies in the accuracy of the results obtained. The performance of a one-fourth-horsepower single-phase induction motor was calculated by the use of the curves described herein and the methods described in appendix II, and is shown with the actual test data for this motor in table I. Examination of this table shows that the calculated and measured results do not differ widely in any respect.

Determination of Maximum Torque

It was known that the point corresponding to maximum torque lay on arc VTL (figure 1) somewhere beyond, but near to, the center of arc VTL. To locate this point precisely would have required the choosing of several points, calculating the data for each point, and then finding the desired point by the process of elimination. It was found, experimentally, that the point corresponding to the maximum torque lay almost midway between the center of arc VTL and the point of tangency between the arc VTL and a line drawn parallel to ML. The point found in this manner located the point of maximum torque closely enough for all practical purposes.

The values of OT, MT, etc., corresponding to the point of maximum torque

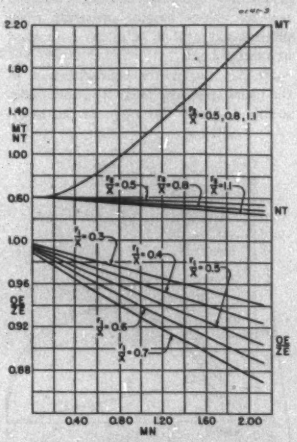

Figure 3. Curves showing data required for performance calculation of single-phase induction motors. (K_r = 0.93)

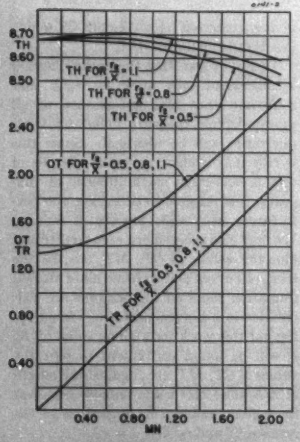

Figure 2. Curves showing data required for performance calculation of single-phase induction motors. (K_r = 0.93)

may also be read and plotted in the form of curves. It was found convenient to plot these values against K_r as shown in figures 4 to 7, inclusive.

The locus of the current vector in an ideal motor follows a circular path but this ideal is deviated from in the case of an actual motor. Usually the circular locus is accurate for points in the normal operating range but some deviation is often noted when calculating the maximum torque. It has been found[1] that the maximum torque as obtained by a brake test is only about 0.92 of the calculated value and so it is necessary to multiply the calculated torque by 0.92 to secure the value to be expected in an actual motor. Aside from this, calculation of the maximum torque is carried out in the same way as for any other point. (See appendix II.)

When the calculation was made upon the motor previously considered the indicated maximum torque was found to check closely (see table I) with the measured value.

Extension of Method to Polyphase Motors

The same diagram may be used to derive a similar set of curves for polyphase motors. For this work MH is again equal to $10K_r$ and the length OO' becomes 0.05 inch for all practical purposes. The inner circle $VTLH$ does not exist and point T lies on $MNLH$. For use with polyphase motors the values of OT, MT, TR, OZ, and ZE are required. These correspond to ON, MN, NR', OZ, and ZE of the single-phase diagram (figure 1).

Thus without a great deal of additional work a set of polyphase curves might be obtained. However, these curves are not believed to be in as usable a form as the "a-b-c" curves described by Branson.[2]

Discussion

It was assumed, in deriving the material contained herein, that the core loss OO' could be given as 0.10 inch in all work and that the ratio of the saturation factors in the main and cross fields was unity. Some such assumption was required or a complete set of curves would have been required for each value of core loss and each ratio of saturation factors. A number of tests were computed and indicated that these assumptions might readily be made. In all use to date these assumptions have been found sufficiently accurate to warrant their use.

The ranges of values of K_r, r_1/X, and r_s/X shown in the sample curves are believed great enough to cover most ordinary motors. As special cases are encountered their data may be recorded and used to build up a more extensive set of curves.

Table I. Comparison of Measured and Calculated Characteristics of a One-Fourth-Horsepower Single-Phase Induction Motor

Quantity	Measured	Calculated
r_1	1.29 ohms	1.30 ohms
r_2	2.51 ohms	2.41 ohms
X	3.60 ohms	3.60 ohms
X_s	51.2 ohms	50.2 ohms
K_r	0.929	0.932
Full-load speed	1,747 rpm	1,737 rpm
Full-load current	4.82 amp	4.81 amp
Full-load efficiency	64.3 per cent	61.5 per cent
Full-load power factor	56.7 per cent	57.2 per cent
Full-load input	292 watts	302 watts
Maximum torque—in per centrated load torque	310	304

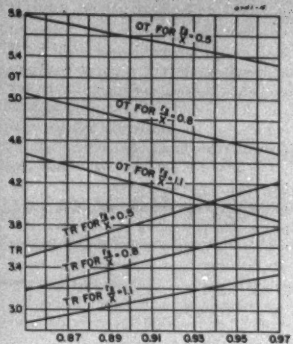

Figure 4

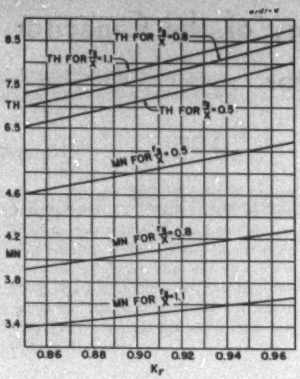

Figure 6

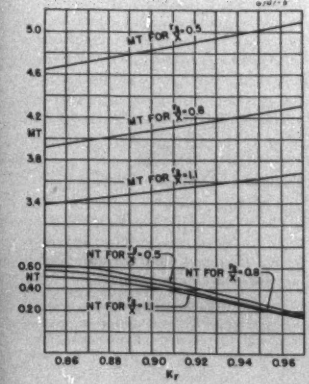

Figure 5

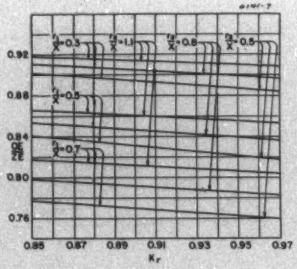

Figure 7

Figures 4–7. Curves showing data required for calculation of the maximum torque which may be expected of a single-phase induction motor

The results obtained by the use of the curves indicate that when the original work is carefully carried out that considerable time may be saved and results are obtained which are as accurate as might usually be obtained by the construction of a special diagram for each motor. In addition, when the curves are plotted any but the most trivial errors are immediately made evident because any errors (except consistent errors) are shown by irregularities in plotting.

Appendix I

Construction of Circle Diagram

Before constructing the circle diagram (figure 1) it is necessary to know the values of the following quantities:

r_1 = stator resistance, ohms

r_2 = rotor resistance, ohms, referred to the stator

Both r_1 and r_2 represent the resistances when the motor is at its normal operating temperature. For a motor designed for a 40-degree centigrade rise, the hot resistance is 1.15 (cold resistance).

X = total leakage reactance, ohms

X_0 = no load reactance, ohms

$$K_p = \frac{\text{permeance of mutual path}}{\text{permeance of mutual and primary leakage paths in parallel}}$$

$$K_s = \frac{\text{permeance of mutual path}}{\text{permeance of mutual and secondary leakage paths in parallel}}$$

$K_r = K_p K_s = (X_0 - X)/X_0$

E = impressed electromotive force, volts

To construct the circle diagram proceed in the following manner. Lay off the horizontal line $O'H = 10$ inches. (Any length may be used but 10 inches is probably the most convenient. The line OE which is passed perpendicularly through $O'H$ at O' is also made equal to 10 inches for convenience.)

Calculate the voltage and current scales.

S_v = voltage scale, volts per inch, $(= E/10)$

S_1 = stator current scale, amperes per inch, $(= E/10X)$

S_2 = rotor current scale, amperes per inch, $(= S_1/K_p)$

Lay off

$$\begin{cases} i_m = E/X_0 \\ O'M = E/S_1X_0 = 10(1-K_r) \end{cases}$$

Using MH as a diameter, construct the semicircle $MNLH$.

$$i_{ms} = \frac{i_m K_r}{2-K_r} \times \frac{\text{saturation factor (cross field)}}{\text{saturation factor (main field)}}$$

Calculate $MV = \frac{E}{S_1X_0} \times \frac{K_r}{2-K_r} \times \frac{\text{saturation factor (cross field)}}{\text{saturation factor (main field)}}$

where the saturation factor is defined as

$$\frac{\text{total ampere turns required}}{\text{ampere turns required for air gap alone}}$$

(The saturation factors for the data shown in the curves have, for convenience, been assumed equal. This is practically true for most motors.)

Locate the locked point L. The distance $LH = MH \sin^{-1}(\tan r_2/X)$

Construct a circle passing through V, L, and H

Construct $OO' = 0.10$ inch (OO' is the main field iron loss current and is equal to main field power loss/ES_1. Its value in most normal motors lies very close to 0.10 inch)

From O lay off $OE = 10$ inches

Choose various points T, draw lines NTH and OT, extending the lines OT to the left of OE a distance $OZ = |(S_1r_1)/S_v| \times OT$

Draw lines ZE.

Appendix II

Calculation of Performance Data

For each point T the following procedure is used.

Secure curves (figures 2 and 3) for desired value at K_T. Select values of MN; read values of TH, OT, and TR for proper r_2/X from figure 2; read values of MT and NT for proper value of r_2/X and OE/ZE for the proper value of r_1/X from figure 3.

1. OT—from figure 2 for proper value of K_r
2. MT—from figure 3 for proper value of K_r
3. MN—selected value, figures 2 and 3
4. NT—from figure 3 for proper value of K_r
5. TH—from figure 2 for proper value of K_r
6. TR—from figure 2 for proper value of K_r

The Cross-Field Theory of the Capacitor Motor

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ANALYSES of the capacitor motor operation date back to the 1920's, a pioneer effort being that of Brüderlin[1] in Europe. Work by Bloch,[2] Biermanns,[3] and others antedates that of Morrill[4] in this country whose analysis has been widely used. All of these have been based on the double revolving field theory, being extensions of that theory to the usual single-phase induction motor.

The cross-field theory has been successfully applied to plain single-phase induction motor analyses by Sumec,[5] Arnold and LaCour,[6] Steinmetz,[7] West,[8] and others, but heretofore no application of this theory has been made to the capacitor motor. The present paper is an exposition of such an analysis.

For the present purpose only two fundamental variations appear in the treatments of the cross-field theory. These concern the speed electromotive forces, built up by rotation of the rotor conductors through the rotor leakage fluxes. To elaborate on this idea, one may take the view that for the same saturation when locked and running, the machine leakage reactance is independent of rotation and that no revolving harmonic fields are present. Of the usual components of leakage flux, namely, slot, zigzag, end, and differential, the stator slot and end connection leakage are stationary in space. By the same reasoning the rotor slot and end connection leakage fluxes rotate with the rotor in space; the zigzag and differential leakage fluxes vary their distribution more or less with different rotor positions, although tacitly an average is assumed. Arnold and West imply that more accurate results are obtained if the assumption is made that the rotor leakage fluxes stand still in space, as opposed to the Steinmetz view that they move with rotation. As a working basis for the former viewpoint which will be used here, the slot, zigzag and end connection components of rotor leakage flux will all be considered as stationary, making up X_s. The differential leakage component should be charged to the stator.

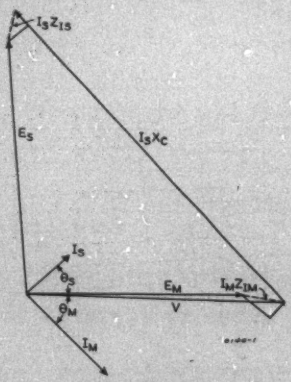

Figure 1. Vector diagram showing stator currents and voltage components

Considerable difference of opinion exists regarding the relative merits of the two classical theories for explaining single-phase induction-motor phenomena. It is not the intention of the present writers to advance the cross-field theory as being wholly superior. Each method has certain advantages and defects. For instance the cross-field theory is blind to the existence of two separate skin effects in rotor conductors and to a pulsating torque superposed on a steady torque. (This latter difficulty could be avoided by the use of instantaneous instead of vector quantities.) But differences in saturation and core losses in the two axes are much easier to visualize with the cross-field theory. And as for its application to the capacitor motor, certain other advantages will be developed and contrasted later.

Fundamental Relationships

The relationship on which the equations are based can be stated briefly as follows (assuming that the stator windings are in space quadrature):

1. The voltage applied to the main winding overcomes a local stator impedance drop and the counter electromotive force built up by the mutual flux of the main axis.

2. The stator current is the resultant of a load component reflected by transformer action from the rotor and a main-axis magnetizing current which may or may not contain an iron loss component.

3. The voltage applied to the quadrature winding (called here the start winding) overcomes the local stator impedance drop of that winding, the reactance or impedance

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1. For all numbered references, see list at end of paper.

7. OE/ZE—from figure 3 for proper value of K_r
8. $MN \times r_s/X$
9. $NT \times r_s/X$
10. $TH - (8)$
11. rpm $= \sqrt{\frac{(10)}{(5)}} \times$ synchronous speed (approximately)
$= \sqrt{\frac{(10)^2+(9)^2}{(5)\times(10)}} \times$ synchronous speed (exact formula)
12. Primary amperes $= (1) \times (7) \times S_1$
13. Secondary amperes $= (2) \times (7) \times S_2$
14. Secondary copper loss (cross field) $= (r_{ss}/K_p)^2 \times r_2 \times [(11)/\text{syn. rpm} \times (7)]^2$
15. Secondary copper loss (main field) $= (13)^2 \times r_2$
16. Iron loss (cross field) $= 0.45$ (polyphase iron loss)
17. Friction and windage loss = previously determined
18. Iron loss (main field) $= 0.50$ (polyphase iron loss)
19. Primary copper loss $= (12)^2 \times r_1$
20. Secondary input $= (7)^2 \times (6) \times E \times S_1$
21. Total input $= (18) + (19) + (20)$
22. Total losses $= (14) + (15) + (16) + (17) + (18) + (19)$
23. Output $= (21) - (22)$
24. Torque (ounce-feet) $= 112.7 \times (23)/(11)$
25. Efficiency $= (23)/(21)$
26. Input, volt-amperes $= (12) \times E$
27. Power factor $= (21)/(26)$

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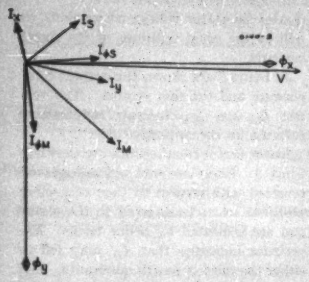

Figure 2. The stator current components and the flux vectors

drop of the capacitor in series with the winding, and the counter electromotive force built up by the mutual flux of the cross axis.

4. The stator current of the cross axis is the resultant of a load component reflected by transformer action from the rotor, and a start or cross axis magnetizing current similar to that of the main winding, but usually differing in magnitude.

5. In the rotor, the main or y-axis current results from two electromotive forces:

(a). The transformer voltage, opposite in phase to the stator counter electromotive force but of the same magnitude if the rotor constants are all considered in main winding terms.

(b). A speed voltage, resulting from the rotor conductors cutting the cross-axis mutual flux, and (as suggested by West and Arnold) the leakage flux of the rotor as well. By Kirchoff's law the vector sum of these voltages and the rotor impedance drop caused by the main axis current, equals zero.

6. In the start or x-axis of the rotor, two electromotive forces, similar to those listed above, are present:

(a). A transformer voltage opposite in phase to the cross-axis counter electromotive force but different in magnitude by the ratio of transformation between start winding and rotor, or start and main windings.

(b). A speed voltage resulting from cutting the main winding mutual and rotor leakage fluxes.

The vector sum of these voltages and the rotor impedance drop of the cross-axis rotor current equals zero.

The four fundamental equations are then (see list of symbols):

Main axis: Stator:

$$Z_M(I_M-I_y)+I_MZ_{1M}=V \quad (1)$$

Start axis: Stator:

$$Z_S(I_S-I_X)+I_S(Z_{1S}+Z_C)=V \quad (2)$$

X-axis: Rotor:

$$\frac{Z_S}{a}(I_S-I_X)+jS[-Z_M(I_M-I_y)+jI_yX_3]=aZ_3I_x \quad (3)$$

Y-axis: Rotor:

$$-Z_M(I_M-I_y)+jS\left[-\frac{Z_S}{a}(I_S-I_X)+jaI_xX_3\right]=-I_yZ_3 \quad (4)$$

These equations are extensions of West's[5] equations for the cross-field theory applied to the plain single-phase induction motor. The terms I_yX_3 and aI_xX_3 in equations 3 and 4, respectively, represent the added effect on the speed electromotive forces of cutting the rotor leakage fluxes. If these are dropped, the fundamental equations reduce to a form which Steinmetz's single-phase motor equations would yield.

By substitution, the stator components of the rotor currents, I_y and I_x, can be eliminated in these four equations, leaving two in terms of the two components of stator current. For further convenience in obtaining a final solution by determinants, the coefficients of these currents can be represented by the A, B, and C constants as shown below. Then:

$$A_1I_M+B_1I_S=C_1 \quad (5)$$

$$A_2I_M+B_2I_S=C_2 \quad (6)$$

where:

$$A_1=S\left[jZ_{1M}-X_3\left(1+\frac{Z_{1M}}{Z_M}\right)\right] \quad (7)$$

$$B_1=-\left[aZ_3+(Z_{1S}+Z_C)\left(\frac{1}{a}+a\frac{Z_3}{Z_S}\right)\right] \quad (8)$$

$$C_1=V\left[S\left(j-\frac{X_3}{Z_M}\right)-\left(\frac{1}{a}+a\frac{Z_3}{Z_S}\right)\right] \quad (9)$$

$$A_2=\left[Z_{1M}\left(1+\frac{Z_3}{Z_M}\right)+Z_3\right] \quad (10)$$

$$B_2=S\left[-aX_3+(Z_{1S}+Z_C)\left(j/a-a\frac{X_3}{Z_S}\right)\right] \quad (11)$$

$$C_2=V\left[\left(1+\frac{Z_3}{Z_M}\right)+S\left(j/a-a\frac{X_3}{Z_S}\right)\right] \quad (12)$$

Then by determinants:

$$I_M=\frac{C_1B_2-C_2B_1}{A_1B_2-A_2B_1} \quad (13)$$

$$I_S=\frac{A_1C_2-A_2C_1}{A_1B_2-A_2B_1} \quad (14)$$

From (1) and (2),

$$I_y=I_M\left(1+\frac{Z_{1M}}{Z_M}\right)-\frac{V}{Z_M} \quad (15)$$

$$I_x=I_S\left(\frac{Z_S+Z_{1S}+Z_C}{Z_S}\right)-\frac{V}{Z_S} \quad (16)$$

For rotor-locked conditions, (13) and (14), reduce to

$$I_M=\frac{V}{Z_{1M}+\left(\frac{Z_3}{1+\frac{Z_3}{Z_M}}\right)} \quad (17)$$

$$I_S=\frac{V}{(Z_{1S}+Z_C)+\frac{aZ_3}{\frac{1}{a}+a\frac{Z_3}{Z_S}}} \quad (18)$$

The counter electromotive forces in the separate windings are:

$$E_M=V-I_MZ_{1M} \quad (19)$$

$$E_S=V-I_S(Z_{1S}+Z_C) \quad (20)$$

The rotor input, or the power transferred across the gap, is the sum:

$$E_MI_y\cos(E_M,I_y)+E_SI_x\cos(E_S,I_x) \quad (21)$$

The power converted to mechanical form:

$$\text{Power across gap by (21)}-(I_y^2+a^2I_x^2)r_3=ST \quad (22)$$

$$\text{Net output = power converted to mechanical form}-(F\&W) \quad (23)$$

The torque in synchronous watts, (T) is the sum:

$$aE_MI_x\sin(E_M,I_x)+\frac{E_S}{a}I_y\sin(E_S,I_y) \quad (24)$$

The stator input is the sum:

$$VI_M\cos\theta_M+VI_S\cos\theta_S \quad (25)$$

The stator losses:

$$I_M^2r_{1M}=\text{copper loss in the main winding} \quad (26)$$

$$I_S^2(r_{1S}+r_C)=\text{copper loss in start winding circuit} \quad (27)$$

$$\frac{E^2M}{r_t}+\frac{E_S^2}{r_{oS}}=\text{iron losses} \quad (28)$$

The rotor losses:

$$I_y^2r_3=\text{copper loss in the } y\text{-axis} \quad (29)$$

$$a^2I_x^2r_3=\text{copper loss in the } x\text{-axis} \quad (30)$$

Some attention should be given to the matter of iron losses. In the double-field theory of Morrill, the iron losses are neg-

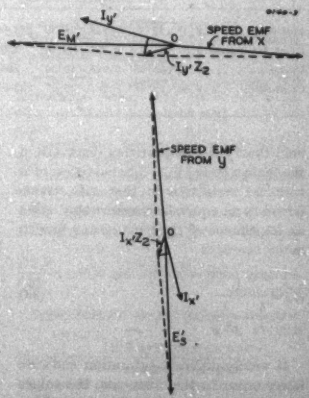

Figure 3. The rotor current and voltage vectors

lected in the equations, but good results are claimed for a correction based on consideration of these losses as external to the motor. In the use of the revolving-field analyses it has been the experience of the present writers that a lack of agreement may result between calculated and test values, particularly in the start winding under running conditions. This may be due to saturation, harmonics, or both, corrections for which are not readily introduced in the equations.

If desired, the iron losses can be considered in the symmetrical-component method of Lyon and Kingsley,[9] or in the method of Punga[10] which rests on the polyphase motor. The work of Y. Hasumi[11] on the symmetrical-component basis indicates a very simple method of introducing the iron losses in Morrill's equations by using for forward and backward impedance, respectively, the terms:

$$Z_f = \frac{1}{\frac{1}{r_0} + \frac{1}{jX_m} + \frac{1}{r_{M/s}+jX_s}} = R_f + jX_f \qquad (31)$$

$$Z_b = \frac{1}{\frac{1}{r_0} + \frac{1}{jX_m} + \frac{1}{r_{M/2-s}+jX_s}} = R_b + jX_b \qquad (32)$$

In any case the labor involved is considerable, the efforts to reduce it, such as by the method of Krondl,[12] or by tabulated form sheets and curves, have met with partial success.

In the method used here with the cross-field theory the magnetizing reactance of the main axis is jX_M. The addition of a core-loss resistance in that axis, transferred to an equivalent series value, gives an impedance of the magnetizing branch as

$$Z_M = \frac{1}{\frac{1}{r_0} + \frac{1}{jX_M}} \qquad (33)$$

If widely different saturation and core losses occur in the cross-axis, the values should be modified but the magnetizing impedances in the two axes take the same form; thus:

$$Z_S = \frac{1}{\frac{1}{r_{0S}} + \frac{1}{jX_S}} \qquad (34)$$

Neglecting the iron losses, with the idea of considering them later as external to the motor, results in the reduction of Z_M and Z_S to jX_M and jX_S, respectively.

Symbols

V = applied volts. Used as reference vector

E_M = the counter electromotive force in the main axis

$Z_{1M} = r_{1M} + jX_{1M}$ = the impedance (local) of the main stator winding

Z_2 = the rotor impedance in main winding terms (local) $= r_2 + jX_2$

E_S = the counter electromotive force of the start or capacitor winding

$Z_{1S} = r_{1S} + jX_{1S}$ = the local impedance of the stator start winding

$Z_C = r_C - jX_C$ = capacitor impedance

I_M = the stator current, main axis

I_S = the stator current, start axis

$I_{\phi M}$ = the magnetizing current, main axis

$I_{\phi S}$ = the magnetizing current, start axis

I_y = the stator component of the rotor current, main axis

I_x = the stator component of the rotor current, start axis

Z_S = the magnetizing impedance in the S-axis

Z_M = the magnetizing impedance in the M-axis

$$Z_S = \frac{1}{\frac{1}{r_{0S}} + \frac{1}{jX_S}}$$

$$Z_M = \frac{1}{\frac{1}{r_0} + \frac{1}{jX_M}}$$

a = Effective start winding turns / Effective main winding turns

S = Actual rpm / Synchronous rpm

s = slip

Vector Diagrams

One advantage of this analysis rests in the graphical picture which can readily be obtained for the physical relationships by vector diagrams. Figure 1 indicates the stator voltage components, as well as the usual positions of the stator currents.

In figure 2 are shown the current components and the flux vectors. The vectors $I_{\phi S}$ and $I_{\phi M}$ indicate magnetizing currents for the respective axis.

Rotor vector relationships are shown in figure 3. Rotor currents and voltages are reversed with respect to their respective positions when transferred to the stator and are indicated by prime terms. Experience indicates that I_X' may fall in either the third or fourth quadrants. The vectors shown here represent the solution of equations 3 and 4.

Summary and Comparative Results

A number of examples have been calculated by this cross-field analysis, one of which is shown in the appendix. The final data are tabulated in tables I and II along with results on the same motor as obtained through other analyses. The method throws light on the phenomena from another point of view and a favorable degree of accuracy is indicated with a competitive ease (or difficulty) of application.

To the engineer who has become thoroughly familiar with the calculation of capacitor-motor performance by the double-field theory, using convenient tabulations of equations, the use of this cross-field analysis will probably appear long and complex. However, considerable experience in handling these equations has led the writers to the belief that for time involved and complexity of calculation there is little to choose between the double-revolving and the cross-field theories. Advantages, then, for this analysis can be found chiefly in the fact that different saturation effects in the two axes can be considered more easily and that the equations result in vector diagrams which are significant in showing the effect of various design changes. This is particularly true in dealing with the conditions necessary for balanced "two-phase" operation, although detailed derivations for this application will not be carried out here. With this analysis a revolving field will exist when:

$$jI_y' = I_X' \qquad (35)$$

$$jE_M' = \frac{E_S'}{a} \qquad (36)$$

Either of these relations is sufficient as indicating that the fluxes are equal and in quadrature. With the rotor currents in terms of the main winding (35) becomes:

Table I. Motor Running With a Slip of Four Per Cent

Method	I_M	I_S	Input and Iron	$I_M^2 r_{1M}$	I_S^2-(r_C+r_{1S})	Rotor Copper	Friction and Windage	Net Output
Morrill	2.47∠50°3′	0.948∠38°46′	221+24	12.3	14.5	11.4	13	177
Lyon & Kingsley	2.57∠55°48′	0.935∠38°40′	239	13.3	14.1	11.8	13	165
Punga	2.57∠56°30′	0.948∠40°50′	234	13.3	14.5	10.9	13	162
Cross-field	2.64∠58°36′	0.954∠39°0′	238+24	14.1	14.7	13.2	13	177 to 179.8

Table II. Starting Conditions

Method	I_M	I_S	Input and Iron	$I_M^2r_{1M}$	$I_S^2\cdot(r_C+r_{1S})$	Starting Torque (Synchronous Watts)
Morrill	$14.2\angle 40°50'$	$6.30\angle 27°55'$	1,796+24	406	401	755
Lyon & Kingsley	$14.0\angle 40°50'$	$6.20\angle 27°50'$	1,750	398	390	728
Punga	$14.2\angle 40°45'$	$6.28\angle 27°40'$	1,790	406	400	708
Cross-field	$14.2\angle 40°0'$	$6.25\angle 27°50'$	1,800+24	408	396	759

$$jI_y = aI_X \quad (37)$$

Also, in main winding terms:

$$jI_M = aI_S \quad (38)$$

When this is used the total revolving magnetomotive forces are indicated as being equal and in quadrature

The problem of obtaining a true revolving field has also been discussed by Specht[13] and Trickey[14] in this country. Some interesting relationships developed by Punga,[10] Krondl,[12] and Wolf[15] do not seem to be generally known. For example when stator main and start windings have equal copper and result in equal saturation, a true revolving field is obtained at some prescribed slip s when

$a = \tan\phi$ (Punga and Krondl)

and

$X_C = (a^2+ja)Z$ (Punga)

wherein:

ϕ = the power factor angle of a two-phase motor with both phases like the main and operating at a slip s

Z = the machine impedance of phase M at a prescribed slip s, for a two-phase motor

Z_0 = the machine impedance similar to Z above, but at a slip of $2-s$

All of these quantities can be obtained from the equivalent network, other equations, or the circle diagram of a two-phase motor.

Trickey's formulas for balanced condition are somewhat longer than those pertaining to the analyses quoted above although they have greater generality. Punga indicates an interesting relationship, in that under the assumptions of equal copper and saturation, I_M becomes zero when for some given value of slip, the capacitor impedance is fixed thus:

$$Z_C = -\frac{Z_0(a^2-ja)+Z(a^2+ja)}{2}$$

No one familiar with the process of designing capacitor motors can be thoroughly satisfied with the present analytical or design tools available to the designer. No convenient expression has been derived for the speed-torque curve nor for the maximum torque that can be developed. The lack of such equations as well as simplified forms of many other relationships, has proved a serious handicap. In the long run such developments result only from the examination of all available theories and viewpoints. It is the hope of the present writers that the cross-field analysis may be a step forward in aiding more useful analyses to be developed.

Appendix I

To illustrate the application of the cross-field theory an example will be worked out using the same motor for which constants are given in Morrill's[6] paper. The values for this four-pole one-fourth horsepower 110-volt motor are:

$r_{1M} = 2.02$
$r_{1S} = 5.12\times 1.18^2 = 7.13$
$r_3 = 4.12$
$r_C = 9.00$
$X_{1M} = 2.79$
$X_{1S} = 2.31\times 1.18^2 = 3.22$
$X_3 = 2.12$
X_C(running) $= -172.0$
$a = 1.18$
$X_M = 66.8$
$X_S = 92.9$

Friction and windage = 13 watts
Iron losses = 24 watts

On any given motor these constants can be obtained by the usual test methods applicable to the ordinary single-phase motor, using each winding independently. Their calculation from a design sheet involves the usual processes pertaining to the single-phase motor found in standard works on design. It is necessary to recall that the machine acts as a transformer in each of its two axes and that consideration must be given (in calculations of rotor constants) to the winding to which these constants are referred. Furthermore, as noted in this example, magnetizing reactance, and rotor resistance and leakage reactance have twice the values by the cross-field theory that they would display for the double revolving field method.

In this example, the use of an equivalent iron loss resistance will be neglected and hence Z_M and Z_S reduce to the respective values of jX_M and jX_S.

Performance will be calculated at a slip of 0.04.

From:

(7) $A_1 = -4.80+j2.00$
(8) $-B_1 = 10.14-j145.9$
(10) $A_3 = 6.367+j4.876$
(11) $B_3 = 139.1+j13.55$
(9) $C_1 = -96.2+j114.7$
(12) $C_3 = 113.5+j85.6$
(13) $I_M = 2.64\angle 58°36'$
(14) $I_S = 0.954\angle 39°0'$
(15) $I_y = 1.55\angle 28°30'$
(16) $I_x = 0.757\angle 131°25'$

The magnetizing current ($I\phi_M$) in the main axis $= I_M - I_y$
$= 0.015 - j1.51$

In the cross-axis ($I\phi_S$): $I_S - I_x = 1.241 + j0.034$

(19) $E_M = 102.67\angle 0°19'$
(20) $E_S = 113.5\angle 91°16'$

The rotor input:

$E_M I_y \cos(E_M, I_y) = 102.67\times 1.55\times \cos(28°30'+0°19')$
$= 140$ watts from the main axis

$E_S I_X \cos(E_S, I_x) = 113.5\times 0.757\times \cos(131°25'-91°16')$
$= 66$ watts from the cross axis

Total input to rotor = 206 watts
The rotor losses:

$I_3^2 r_3 = 1.55^2\times 4.12$ or 9.9 watts
$a^2 I_x^2 r_3 = 1.18^2\times 0.757^2\times 4.12$ or 3.3 watts
Friction and windage = 13.0 watts
Total rotor losses 26.2
Net output = 206 − 26.2 or 179.8 watts

The stator input:

$VI_M \cos\theta_M = 110\times 2.64\times \cos 58°36'$
$= 151$ watts
$VI_S \cos\theta_S = 110\times 0.954\times \cos 39°$
$= 82$ watts
Total input = 233 watts

The stator losses:

$I_M^2 r_{1M} = 2.64^2\times 2.02$ or 14.1 watts
$I_S^2(r_{1S}+r_C) = 0.954^2(7.13+9)$ or 14.7 watts
Total stator losses = 28.8

Note that iron losses have been neglected throughout rather than calculated as in equation 28 and considered with the stator losses.

Output from input − losses = 233 − 28.8 − 26.2 or 178 watts.

This checks fairly well with rotor output of 179.8 watts, as calculated.

The torque from (24),

$1.18\times 102.67\times 0.757\times \sin 131°6' = 69.0$ synchronous watts

$\frac{113.5}{1.18}\times 1.55\times \sin 119°46' = 129.0$ synchronous watts

Total torque, in synchronous watts = 198.0

$\text{Ounce feet} = \frac{112.7\ \text{synchronous watts}}{\text{synchronous rpm}}$

The power converted to mechanical form $= ST$
$= 0.96\times 198$ or 190 watts
The output = 190 − 13 (friction and windage) = 177 watts

Some Insulator Designs Require Special Features to Insure Radio Quietness

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Synopsis: The suggested requirements for radio-free pin-type, switch and bus, and suspension insulators, if acceptable, indicate and justify from a factory testing and production viewpoint, the following conclusions as regards existing standard designs:

1. For distribution voltages up to 4,400 or even 5,500 volts, the small one-piece pin-type insulators used require no "radio-proofing", even on solidly grounded pins.

2. If there is 6 to 12 inches of crossarm in series with small one-piece pin-type insulators on low-voltage distribution lines up to 13 kv, no "radio-proofing" is needed on the insulators.

3. Standard untreated pin-type insulators used on 17 to 69-kv distribution and transmission lines have radio noise-influence voltages in the order of several thousand microvolts at a test potential about ten per cent above the usual line-to-ground voltages. "Radio-proofed" pin-type insulators, readily meeting reasonable requirements for freedom from radio interference, are available for use on lines in this voltage range.

4. Standard cemented pin-and-cap switch and bus insulators up to the 69-kv rating, with the exception of the 66-*S*-class, readily meet the suggested requirements for freedom from radio interference without any special "radio-proofing" treatment; they are inherently quiet.

5. Standard switch and bus insulators for the 66-*S*-class and the 115-kv and higher-voltage classes may require "radio-proofing" or other precautions to meet the suggested abnormally low requirements. These insulators with slight changes can be made to meet these requirements readily.

6. Regular cemented pin-and-cap suspension insulators of modern manufacture readily meet the suggested requirements for freedom from radio interference without any form of "radio-proofing"; they are inherently quiet.

RADIO interference originating on electrical power lines and substations has been studied extensively during the past 10 or 15 years by both the utility engineers and the manufacturers of equipment and materials used in construction. While it is the responsibility of the former to utilize properly the materials available for building their lines, they cannot construct a line or substation which is better than any of its component parts. Therefore, at least part of the responsibility for radio-free power lines and substations is passed on to the manufacturers of materials used in their construction.

Primarily, a power line or substation consists of several conductors which are mechanically held in place and electrically isolated from ground and from each other by means of insulators. The several conductors have a potential with respect to each other and also with respect to ground. One end of an insulator is at the potential of the attached conductor while the other end of the insulator may be at ground potential, or it may have supplementary insulation to ground such as a wood crossarm or a section of a wood pole.

In a three-phase system with a grounded neutral the maximum voltage which can appear across an insulator is the line-to-line voltage divided by 1.732. With wood in series with an insulator to ground, the voltage across the insulator itself may be somewhat less than indicated above. In a three-phase system with an ungrounded neutral an accidental grounding of one of the conductors may place the full line-to-line voltage across the insulators of the other two phases. But this is an abnormal condition which would occur only rarely and then would undoubtedly be corrected as soon as possible. Therefore, the greatest voltage which would normally appear across an insulator in a three-phase system is 0.577 of the line-to-line voltage. For convenience, this voltage is often called the "operating voltage" of the insulator.

Insulators as a Source of Radio Interference

If a power line or substation is to be free from radio interference, it is essential

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Thus by three different approaches outputs of 179.8, 178.9, and 177 watts are obtained. The discrepancies are largely due to slide rule error as a ten-inch slide rule was used throughout.

With a starting capacitor of 3 ohms resistance and 14.5 ohms reactance, the starting conditions can be calculated as shown below:

From (17) $I_M = 14.2 \angle 40°0'$

(18) $I_S = 6.25 \angle 27°50'$

A convenient method of determining I_y and I_z is to substitute the numerical values of I_M and I_S in equations 1 and 2 respectively.

Then,

$$I_z = \frac{j78.6\, I_S}{4.86 + j81.1} \text{ or } 6.06 \angle 31°20'$$

This is in terms of *S* winding; in terms of *M*:

$I_z = 1.18 \times 6.06$ or 7.15 amperes

Similarly:

$$I_y = \frac{j66.8 I_M}{4.12 + j68.92} \text{ or } 13.8 \angle 36°34' \text{ amperes}$$

The counter electromotive force

$E_M = jX_M(I_M - I_y)$

$= 63.6 \angle 10°47'$

$E_S = jX_S(I_S - I_z)$

$= 38.8 \angle 57°0'$

The starting torque:

$$aE_M I_z \sin (E_M, I_z) = 1.18 \times 63.6 \times 6.06 \sin 42°7' \text{ or } 306$$

$$\frac{E_S}{a} I_y \sin (E_S, I_y) = \frac{38.8}{1.18} 13.8 \sin 93°34' \text{ or } 453$$

In synchronous watts: 306+453 or 759

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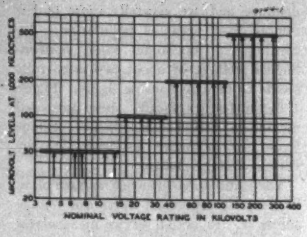
MICROVOLT LEVELS AT 1000 KILOCYCLES
500
200
100
50
20
3 4 5 6 8 10 15 20 30 40 60 80 100 150 200 300 400
NOMINAL VOLTAGE RATING IN KILOVOLTS

Figure 1. Proposed maximum radio noise-influence voltage levels for "radio-free" insulators

that the insulators used in its construction will not cause disturbance under normal operating conditions. On the other hand, it must not be assumed that the use of "radio-free" insulators will prevent radio disturbance from being generated by the other components used in construction.

The realization that certain types of insulators have been responsible for part of the radio noise emanating from power lines and substations has been the incentive for progressive insulator manufacturers to develop insulators which cannot cause radio disturbances when properly placed in service. Since the high-voltage pin-type insulator was the principal offender, the pioneer investigations were made on this type. (See "Behavior of High-Voltage Insulators on Radio Test," by Charles J. Miller, Jr., in *Electrical World*, March 25, 1939, pages 45–8.)

Fundamentally, the radio interference originating from insulators is caused by an electrically overstressed condition of the air adjacent to certain regions of the insulator. Fortunately, overstressed air, besides giving rise to radio interference, makes its presence known by a visual phenomenon commonly called corona, or corona discharge. This visual corona enabled the pioneer radio-interference investigators to locate the regions of electrical overstress on the pin-type insulator. It was found that these principal regions were at the conductor and tie wire and in the pin hole where thin layers of air were being subjected to intense electric fields. The obvious solution to this problem was to eliminate the air from these critical regions or to alter the design of the insulator in such a way that the intense dielectric field of the insulator between the pin and the conductor and tie wire existed wholly within the dielectric medium of the insulator and not across these layers of air.

Methods of Radio-Proofing Insulators

A conduction paint was developed which could be brushed around the head of the pin-type insulator and in the pin hole. This conduction paint altered the electric field in the critical regions and reduced the noise level of the insulator by many times. However, this paint was too temporary a remedy to be a final solution of the problem. Progressive manufacturers were not satisfied with a temporary remedy and continued the search for a permanent treatment which would last the life of the insulator.

The pin-hole problem was readily solved by cementing a zinc thimble or metal insert into the pin hole. The cement, being a semiconducting medium readily transfers the flux lines from the inner surface of the porcelain to the metal thimble.

The top of the insulator presented a bigger problem and numerous devices were used to attain the desired end. Certain designs were brought out with cemented metal hardware on top of the insulator. Some of these designs have excellent radio properties. Other designs have metallized coatings bonded to the critical area of the insulator by various means. The most recent designs utilize conducting glazes in the critical regions. This type of treatment is being very widely adopted on pin-type insulators because of its satisfactory characteristics and ease of application.

The EEI-NEMA-RMA Measuring Circuit

Along with the advancement of the art of "radio-proofing" insulators came the development of a factory means of measuring the radio-interference properties of equipment and insulators. In the early days of the art, each manufacturer devised his own method of testing and, consequently, when the time came to compare results, it was found that there was no common yardstick for measuring radio interference.

In the meantime the Edison Electric Institute, National Electric Manufacturers Association, and Radio Manufacturers Association were faced with the problem of measuring all sorts of radio interference from all types of equipment. To study the problem in general, the three organizations appointed a committee which came to be known as the "Joint Co-ordination Committee on Radio Reception of EEI, NEMA, and RMA." This committee devised a method of measuring radio noise and established

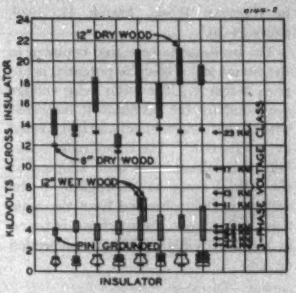

Figure 2. Kilovolts necessary to produce a radio noise-influence voltage of 50 microvolts on small one-piece pin-type insulators with the pin grounded and with wood in series with the insulator

various standards for these measurements. A pamphlet entitled "Methods of Measuring Radio Noise" was published in December 1935 by the joint committee. The latest publication by this committee (EEI Publication No. G9—NEMA Publication No. 107—RMA Engineering Bulletin No. 32) is entitled "Methods of Measuring Radio Noise, 1940" and was published in February 1940.

The joint committee devised a circuit to be used for high-voltage devices. This circuit was adopted by leading insulator manufacturers in 1937 and has been the recognized method of test since. (See "Establishes Method of Measuring Radio Interference," by Charles J. Miller, Jr.,

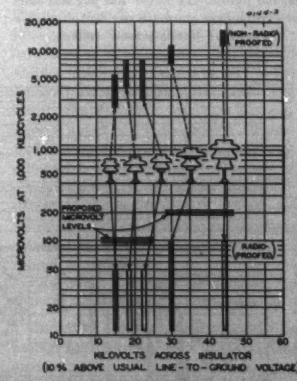

Figure 3. Radio noise-influence voltages from regular pin-type insulators at a test voltage about ten per cent above the usual line-to-ground voltage

in *Electrical World*, March 11, 1939, pages 48–50.)

The insulator to be tested is placed in the circuit and a 60-cycle potential is applied across it. The radio noise voltage generated by the insulator is measured with the radio noise meter and is expressed in "microvolts." The term "radio noise-influence voltage" has been adopted as the official name to be applied to the voltage reading obtained from the radio noise meter when the specimen is tested in the EEI-NEMA-RMA recommended circuit.

Requirements for Radio-Free Insulators

To be free of radio interference, insulators must meet certain requirements when tested in the EEI-NEMA-RMA circuit. Based on field experience and known characteristics of available "radio-free" insulators, the majority of manufacturers of high-voltage insulators have suggested radio noise-influence voltage levels which will insure freedom from interference of various classes of insulators under service conditions.

Radio interference originating on a power line may be transferred to a nearby antenna by direct coupling between the power line and antenna, or it may be carried an appreciable distance along a low-voltage distribution line and then be transferred to a receiving antenna. (See "Sources of Radio Interference and How to Eliminate Them," by Paul M. Ross, in *Electric Light and Power*, September 1939, pages 38–9.) In the latter case, coupling must exist between the power line and the low-voltage distribution line and also between the distribution line and the antenna.

The farther the distribution line or the antenna from the power line, the smaller is the transfer of radio interference. In general, the higher the voltage of a power line, the greater is its distance from low-voltage distribution lines and antennas. Accordingly, it seems quite reasonable to select a maximum permissible microvolt radio noise level in keeping with the voltage of the line.

Low-voltage distribution lines up to the 13-kv class cover widespread areas and are more or less closely coupled to distribution networks supplying individual homes. It is felt that a maximum radio noise-influence voltage of about 50 microvolts for insulators used on these lines will insure freedom from radio noise provided the radio noise-influence voltages of all other components of the line are also below equally satisfactory levels. Obviously, disturbance on a power line arising from sources other than insulators cannot be blamed on the insulators, nor can "radio-free" insulators suppress radio interference arising from these other sources.

Power lines in the 17 to 34.5-kv classes are, in general, not as closely coupled to the distribution networks and, therefore, a maximum radio noise-influence voltage of about 100 microvolts seems to be a reasonable level. In the range from 46 to 115-kv classes, a level of 200 microvolts should provide adequate protection from radio interference. Transmission lines in the 138 to 287-kv classes seldom parallel lower-voltage lines for any appreciable distance and are generally more or less remote from areas of population. Accordingly, a maximum radio noise-influence voltage of about 500 microvolts seems to be a reasonable figure. Figure 1 illustrates graphically these proposed maximum radio noise-influence voltage levels for radio-free insulators for the various voltage classes.

The radio noise-influence voltage of an insulator is dependent upon the voltage across it. In actual service an insulator is subjected to the line-to-ground or operating voltage. Every transmission line has a "nominal" voltage rating which may be slightly different than the actual voltage. Furthermore, the actual voltage on a transmission line may be higher at the sending end than at the receiving end. To compensate for possible voltage variations from the nominal value, it seems quite logical to subject the insulator to a test voltage about 10 per cent higher than the nominal line-to-ground voltage when testing it in the EEI-NEMA-RMA circuit.

With a standard method for measuring the radio noise-influence voltage produced by an insulator and with a set of requirements which must be fulfilled by a "radio-free" insulator, the insulator manufacturer has at his disposal a radio-interference yardstick with which he can judge the merits of the insulators he manufactures.

Radio Noise-Influence Voltages of Various Types of Insulators

Having a definite yardstick for measuring the radio interference properties of insulators, a survey of available insulators of all types provides an interesting study. Briefly, such a study leads to the conclusion that certain types of insulators which have been manufactured for years require no special "radio-proofing" to meet the suggested requirements for freedom from radio interference; they are inherently quiet.

Conducting glazes provide effective "radio-proofing" on pin-type insulators. However, it does not necessarily follow that conducting glazes are required on all designs and classes or that they provide the only effective means of "radio-proofing" an insulator. For example, pin-type insulators which are "radio-proofed" with metallized coatings or cemented hardware are available.

Small One-Piece Pin-Type Insulators

Small one-piece pin-type insulators are commonly used on low-voltage distribu-

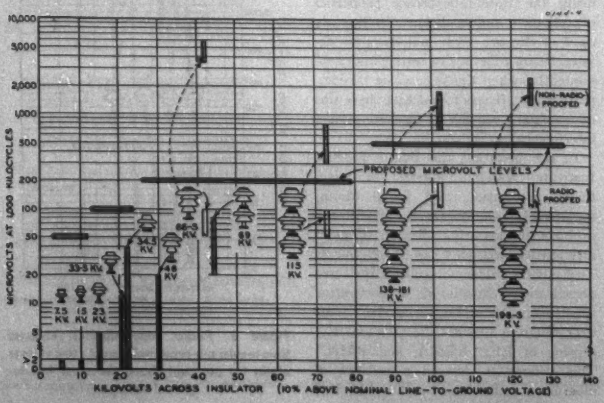

Figure 4. Radio noise-influence voltages from regular pin-and-cap switch and bus insulators at a test voltage about ten per cent above the nominal line-to-ground voltage

tion circuits. In many cases these insulators are mounted on wood crossarms. This provides a section of wood in series with the insulator to ground or between phases. The voltage divides in proportion to the impedance of the insulator and that of the section of wood, thereby reducing the potential across the insulator from the operating voltage to a lower value. This means that the radio noise-influence voltage to ground from a given insulator will be lower with a section of wood in series with it than with the pin grounded.

A "radio-proof" power line is one which does not interfere with radio reception in nearby homes. It makes no difference how the "radio-proofing" is accomplished so long as the desired results are attained. Small "radio-proofed" pin-type insulators are available for even the lowest-voltage lines. However, before proceeding with the application of "radio-proofed" insulators to these voltage lines, it might be well to stop for a moment and consider the limitations of the old reliable "non-radio-proofed" insulators used for years on the lower-voltage lines.

Figure 2 shows the kilovolts across the insulator necessary to produce a radio noise-influence voltage of 50 microvolts on several different sizes of insulators. Since no two insulators of even the same size give exactly the same results on test, the bands in which all of the test values fall are given. With the pin grounded, the 50-microvolt level falls between 3 and 6 kv for all of the insulators.

Numerous tests were made with 12 inches of dry wood in series with the insulator and a wide range of kilovolt levels was found, ranging from about 12 to 21 kv. A single test was made on each size insulator with 6 inches of dry wood in series with the insulator and the kilovolt levels ranged from 11.5 to 13.5 kv.

Tests were made on one size insulator with 12 inches of very damp wood in series with it. Two samples of wood crossarm were used. These crossarms had been lying outside the laboratory all winter and accordingly were very wet inside, probably much more so than crossarms in service on poles. In spite of this, these crossarms added 2 or 3 kv to the 50-microvolt level voltage.

In any power line, the voltage across the insulator is determined by the operating voltage of the line. In a three-phase system, the voltage across the insulator is generally considered to be the line-to-line voltage divided by the $\sqrt{3}$. It is this voltage which may cause radio interference from the insulator. In figure 2 the line-to-neutral voltage is shown for several nominal operating voltages.

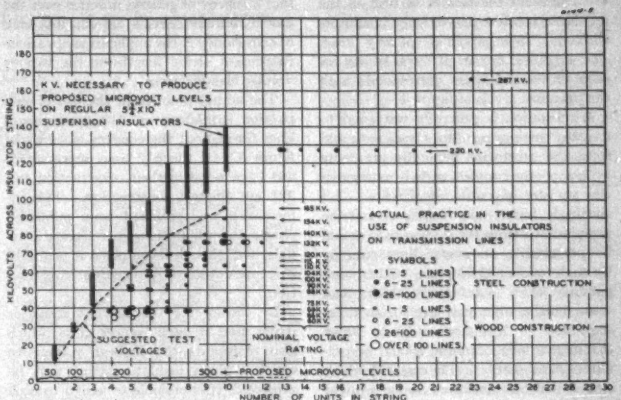

Figure 5. A comparison between the voltages applied to suspension insulator strings in actual practice and voltages necessary to produce the proposed microvolt levels

Up to and including 4,400-volt lines, not a single insulator would produce as much as 50 microvolts of radio interference even with the pins bonded. Accordingly, the ordinary plain insulator used for years is entirely adequate as regards radio interference and nothing can be gained by using "radio-proofed" insulators on 4,400-volt and lower-voltage power lines.

When there is 6 to 12 inches of dry crossarm in series with the insulator, the 50-microvolt level occurs at such a high voltage that even 13 and 17-kv lines are free from radio interference with the ordinary plain insulator. The actual improvement provided by the wood depends almost entirely upon its moisture content. Real wet wood, a condition existing for infrequent and short periods, may provide only a few kilovolts improvement. In figure 2, wet wood adds from 2 to 4 kv to the 50-microvolt level voltage, but this is enough to assure freedom from radio disturbance on 7.5-kv lines. Crossarms in service exposed to the air would probably never be as wet as the arms tested. Accordingly, it seems reasonable to expect that under average conditions 12 inches of wood in series with the insulator will assure freedom of radio interference from power lines operating at 7.5 kv to ground (13 kv, three phase) and below without the necessity of using "radio-proofed" insulators.

High-Voltage Pin-Type Insulators

The standard pin-type insulators used on 17 to 69-kv distribution lines have radio noise-influence voltages in the order of several thousand microvolts at a test voltage ten per cent above the nominal line-to-ground voltage for which the insulators are commonly used. Figure 3 shows the range of radio noise-influence voltages for five of the popular sizes of pin-type insulators. The proposed microvolt levels are also shown. Obviously, the conventional pin-type insulator cannot qualify as a radio-free pin-type insulator.

Dry wood crossarms in series with these insulators will reduce the noise level a marked degree but in general the reduction is not sufficient to approach the suggested microvolt levels. The only practical permanent solution for the radio-interference problem on the higher-voltage distribution lines is to use "radio-proofed" pin-type insulators which have been manufactured for the purpose. Several types of "radio-proofed" insulators which readily meet the suggested requirements are available. The use of conduction paint or other temporary means of suppression offer an opportunity for satisfactory treatment of existing lines where reinsulation by improved designs cannot be justified.

Switch and Bus Insulators

Generally accepted apparatus voltage ratings have been assigned to the various sizes of switch and bus insulators. The radio noise-influence voltages measured on the various switch and bus insulators at a 60-cycle test voltage about ten per cent above the voltage rating divided by the $\sqrt{3}$ are shown by the bands in figure

4. These are the results of test on the regular cemented pin-and-cap insulators with no "radio-proofing" of any kind. The suggested microvolt levels shown for each of the insulators corresponds with the proposed levels of figure 1.

A substation is generally restricted to a rather small area. Lines leading to and from the substation generally are more or less poorly coupled with it as regards the transfer of radio interference. Accordingly, higher microvolt levels may be permissible within the station than would be permissible on power lines running through residential districts. Other components of a substation which tend toward higher microvolt levels than those suggested for insulators seem to prove that higher levels can and should be permitted in substations. The ease with which switch and bus insulators can be brought to the suggested microvolt levels appears to be the only justification for these ultraconservative values being considered.

A study of figure 4 reveals the important fact that every one of the switch and bus insulators up to and including the 69-kv class, with the exception of the four-part single-unit 66-*S*-kv insulator, has a radio noise-influence voltage which is less than the suggested allowable value for "radio-free" insulators. This means that regular switch and bus insulators up to the 69-kv class, excepting the 66-*S*-class, do not need any special "radio-proofing" treatment to make them quiet; they are inherently so.

The 66-*S*-class insulator definitely requires a "radio-proofing" treatment if the suggested microvolt level is to be met. It has been successfully "radio-proofed" by slight revisions and its radio noise-influence voltage is well below the permissible 200 microvolts at a test voltage 10 per cent above the nominal line-to ground voltage. These revised designs are now the standard products of leading manufacturers.

The stacking insulators used in the 115-kv class and above give radio-influence voltages which exceed the proposed microvolt levels. To meet these suggested levels, slight revisions have been necessary to "radio-proof" these insulators in manufacture.

Suspension Insulators

No definite voltage ratings have been assigned to suspension insulators. In fact a survey of general practice over the entire country reveals an amazing lack of consistency in the application of various suspension string lengths to the various voltage classifications.

The actual practice in the use of suspension insulators on 612 transmission lines throughout the country is shown in figure 5. Of the 612 lines represented, 291 have wood in their construction and 321 are all-steel construction. This information was gathered from published charts and tabulations in technical journals, and, though incomplete, it probably is representative of existing construction.

By considering the shortest insulator string used in each voltage class, which also represents the highest voltage to which a given insulator string may be subjected, it is possible to assign to each string length a maximum microvolt level which is consistent with the proposed levels of figure 1. The proposed microvolt levels assigned to each string length are indicated at the bottom of figure 5.

The kilovolts necessary to produce the proposed microvolt levels for the different string lengths of regular cemented pin-and-cap suspension insulators of modern manufacture are shown by the bands in figure 5. These values are given only for string lengths up to ten units as this was the upper limit of testing equipment available at the time the tests were made. Higher-voltage equipment is now available.

In every case, the minimum kilovolts necessary to produce the proposed microvolt level is well above the highest voltage to which the given string would be subjected in service. In other words, at the highest operating voltage the radio noise-influence voltages from standard unaltered and untreated suspension insulators are less than the proposed microvolt levels for freedom from radio interference. Accordingly, it seems unnecessary to apply special treatment to standard cemented pin-and-cap suspension insulators; they are inherently "radio-free."

It is possible to assign to each string length a 60-cycle test voltage which represents the severest conditions to which the string may be subjected. To be consistent the test voltage assigned to each string length should bear some relation to other string lengths. One such set of assigned values is connected by a curve in figure 5. This curve is more or less the upper envelope of the points representing the suspension insulator applications. There seems to be no reason for placing this curve much higher as this would increase the severity of the radio test on suspension insulators and it would benefit no one.

In spite of the excellent radio characteristics of suspension insulators, conduction glaze has been applied both at the cap and in the pin hole. The cap treatment has increased the visual corona voltages materially. The treatment in the pin-hole area, however, has not proved as successful as at the cap, and in long strings the corona voltage at the pin of the line unit is in general lower than the corona voltage for the corresponding nontreated suspension insulators. The radio noise-influence voltages are generally about the same for the treated and nontreated insulators but there seems to be a tendency for the treated insulators to come lower. The failure of the conduction glaze treatment to provide the improvement found in its other applications is probably due to the configuration of the dielectric field in the pin hole and the inability of the conducting glaze, which must necessarily be applied only to the surface of the porcelain, to alter this field sufficiently to relieve the stress on the adjacent air.

On practically all lines, there are conductor and hardware members operating at high voltages, including clamps or other means for attaching the conductors to the insulators, reinforcing devices such as armor rods, vibration dampers, and similar special items. On a "radio-free" transmission line there must be no disturbances originating from the hardware. When such disturbances occur, they are caused by electrically over-stressed air adjacent to sharp corners or edges of the hardware. Such sources of noise generate a great amount of radio disturbances. Laboratory tests show that when such a disturbance starts, the radio noise-influence voltage jumps abruptly to several hundred microvolts and a small increase in the 60-cycle test voltage is accompanied by a big increase of the radio noise. It is essential in "radio-proofing" a transmission line to be sure that the hardware is adequately designed as well as the insulators.

Performance Calculations on Repulsion Motors

P. H. TRICKEY
MEMBER AIEE

Synopsis: A method of calculating the performance of repulsion motors is developed for the purpose of predetermining the torques and currents, especially for repulsion-start, induction-run motors during the starting period. The method is based on the cross-field theory presented by H. R. West. It is developed along similar lines to the single-phase calculation method presented by C. G. Veinott,[2] and is intended for use in connection with it. The paper presents also the results of investigation showing the effects of varying the several motor constants, and a method of determining the effect of brush resistance.

IN a paper presented a number of years ago, H. R. West developed methods of calculating the performance of single-phase induction and repulsion motors, based on the cross-field theory. In 1932, C. G. Veinott further developed the method for single-phase motors, from the point of view of routine calculation, and presented a calculation sheet for this purpose which is now in use in the engineering departments of many motor companies.

It is the purpose of this paper to develop the repulsion-motor method in the same manner, and to offer a calculation sheet of the same general form as that presented by Mr. Veinott. It has been developed particularly for use in conjunction with it in the design of repulsion-start, induction-run motors, but may, of course, be used for ordinary repulsion-run motors.

Repulsion-Motor-Performance Calculations

The circuits of the repulsion motor may be represented by figure 1. The development of the method consists in writing the equations of voltages in the three circuits of the motor in accordance with Kirchhoff's law, and solving these equations for the motor currents and torque. The problem then becomes one of algebraic transformation into a form most suitable for routine solution. This particular derivation has had several important objectives. The first, of course, is speed. Repulsion motors are usually fractional horsepower, and unless the calculation is quickly and easily made, it is more economical to rewind a sample motor once or twice. The second objective is simplicity and clarity. It often happens that repulsion-motor designs come at infrequent intervals in the course of designing many other types, usually split-phase or polyphase. It is desirable that the designer be able to proceed immediately into a calculation without any preliminary "brushing up" on the method. Another objective in this case is the possibility of calculating torques and speeds without calculating currents or inputs. This is desirable with repulsion-start, induction-run motors, in obtaining the starting and pull-up torques.

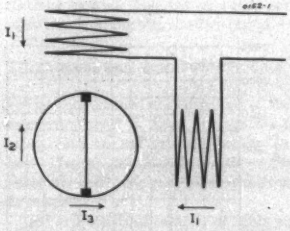

Figure 1. Schematic diagram of the repulsion motor

As will be shown later, one of the characteristics of the repulsion motor is that its starting torque is a maximum with no current in the coils short-circuited by the brushes. This would occur with infinite brush resistance. The method has been so arranged that a simple calculation with infinite brush resistance is easily made as a check on the loss of torque due to the short-circuit current.

All of the assumptions and details in the papers of Mr. West and Mr. Veinott hold for this method also. The angle of hysteretic lag between the flux and the magnetomotive force is assumed to be zero. Sinusoidal voltages and currents are assumed. The flux is assumed proportional to the current and magnetomotive force.

The method involves choosing a value of speed, and calculating the performance at that speed. The currents and torques are calculated independently of each other. Although it is possible by this method to obtain a vector solution for the primary current, and from the power component derive the watts input, it was felt as in the case of Mr. Veinott's calculation sheet that a more accurate value would be obtained by adding the losses to the output.

Due to the most frequent use of this method being at the lower speeds and greater currents, it was decided to subtract the iron loss from the output in the same manner as the friction loss.

There is one point in the calculation where it is assumed that the primary and secondary reactances are equal, that is, $x_1 = x_2$. This occurs in calculating the constant H_1,

for $x_1 \neq x_2$,

$$H_1 = \frac{r_1}{X_0}\left(1+\frac{r_2}{r_2}\right)+\frac{r_2}{X_0}\left(\frac{X_m+x_1}{X_m+x_2}\right)$$

for $x_1 = x_2$,

$$H_1 = \frac{r_1}{X_0}\left(1+\frac{r_2}{r_2}\right)+\frac{r_2}{X_0}$$

For all ordinary work the second formula is used, but if desired the first one may be followed. Figure 2 shows the small change in performance when the reactances are not equal.

Figure 12 shows the form of the calculation sheet and an illustrative example.

The Effect of Changing the Motor Constants

A number of calculations have been made showing the effect of changing the different constants of the motor. Figure 2 has already been mentioned showing the effect of transferring the reactance from stator to rotor or vice versa. Figure 3 shows the effect of increasing or decreasing the total leakage reactance. The improvement in a motor with increased numbers of slots is largely the result of decreased reactance.

The speed-torque curves of figure 4 show little change with variation of the open-circuit reactance, the greatest change being in the current and power factor. However, it will be noticed that as X_0 decreases, there is finally a reduc-

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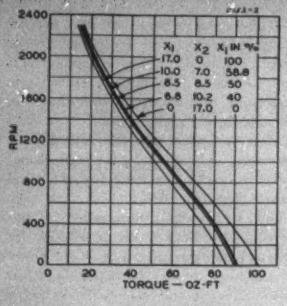

Figure 2. Effect of distribution of leakage reactance between primary and secondary

tion in torque, and it will be found that as the size of the motor decreases or the number of poles becomes greater, this effect will become quite prominent. This is the result of the increased primary impedance drop which reduces the voltage remaining to supply the air-gap flux.

No curves are given for the effect of changing the motor turns, for the result is the same as that obtained by varying the applied voltage, that is, the torques vary as the square of the voltage. Also, any change in the primary resistance has much the same effect, that is, the impedance drop varies and with it the remaining useful voltage.

Figure 5 showing the effect of secondary resistance is somewhat different than for the induction motor, for even at standstill the torque is decreased with increased rotor resistance.

Figure 6 illustrates several interesting points. As will be shown later, r_2 is the resistance of the useful part of the armature, which is made up of a number of coils in series with the brushes. r_3 is the resistance of the short circuits caused by the brushes, and is usually made up of one coil only, in series with two halves of a brush. The several short-circuited coils have the effect of operating in parallel. Figures 6 and 7 show very clearly that the higher r_3, the more desirable the speed-torque characteristics. Whereas, figure 5 shows that r_2 should be decreased for improvement. The problem then is one of increasing r_3 without at the same time increasing r_2. To do this by increasing the resistance of the brush itself is not advantageous beyond a certain point, for although r_3 may be increasing much faster than r_2, a point will be reached when any further increase in r_3 will result in too low pull-up torque. The usual method is to increase the number of coils and commutator bars, which makes the brush resistance a smaller percentage of r_2, and a greater percentage of r_3. It will be noted that r_3 has comparatively little effect on the torque at 75 per cent of synchronous speed, which is the usual operating speed of the short-circuiter, while effecting the starting torque almost directly.

A point of academic interest is obtained with r_3 very low and equal to r_2. Under these conditions, the motor has no starting torque, and operates exactly like a single-phase induction motor. This abnormal condition would be obtained with very wide low-resistance brushes, or with double the regular number of brushes, spaced 45 electrical degrees apart.

It might be noted at this point, that r_3 inherently varies with commutator position as the number of coils short-circuited by the brush changes. For instance, suppose the brush thickness

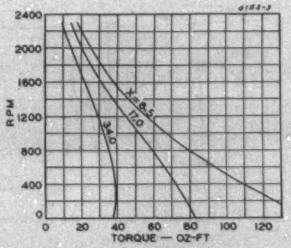

Figure 3. Effect of leakage reactance

equals one commutator bar. In this case, when the brush is exactly over the bar no coils are short-circuited, and r_3 is infinite. When the brush is touching two bars, there is one coil short-circuited under each brush. Thus, r_3 varies from some definite value to infinity, as the rotor passes through one commutator bar pitch. This is the usual case, but supposing the brush is a little wider and can touch three bars at some positions. In this case, r_3 will vary from the worst or lowest value of the narrow brush, to a value which is only half as much.

The most outstanding variable in the repulsion motor is the brush shift. Figures 8 and 9 illustrate the effect on the starting and running torques, respectively. It would, of course, be desirable to operate at the point of maximum starting torque. However, the actual dimensions of the brush shift are not very large, particularly in four-, six-, and eight-pole motors, and to be safe under conditions of manufacturing variations, the brush shift is usually chosen on that side of the peak value corresponding to more shift. This side of the curve is less steep, and if the brush location is not exactly correct, the starting torque will not decrease as much.

Brush Resistance

There is no difficulty in calculating the primary resistance and the reactances of the repulsion motor, but it might be well to discuss the calculation of the secondary resistances r_2 and r_3. One of the difficulties in the design of repulsion motors has been the calculation of that part of r_2 and r_3 caused by the contact resistance of the brushes.

$$r_{2t} = \left[\frac{CKw_m}{2\,tpc\,Kw_{2t}}\right]^2 \frac{r_c}{N_c} \qquad (1)$$

$$r_2 = \left[\frac{CKw_m}{2\,tpc\,Kw_m N_c/a}\right]^2 \frac{\dfrac{r_c N_c}{a} + \dfrac{r_b A}{A_b}}{a} \qquad (2)$$

$$r_3 = \left[\frac{CKw_m}{2\,tpc\,Kw_m}\right]^2 \frac{r_c + \dfrac{r_b A}{A_b}}{a} \qquad (3)$$

where

r_{2t} = rotor resistance referred to the primary when all commutator bars are short-circuited together, and operating as an induction motor
r_2 = rotor resistance as a repulsion motor
r_3 = rotor resistance of the short-circuited coils
r_c = resistance per coil of rotor
r_b = brush contact resistivity, see figure 10
CKw_m = total effective series conductors of primary
tpc = turns per coil in rotor
N_c = number of coils on rotor
a = number of parallel paths in rotor
Kw_{2t} = rotor winding factor (pitch times distribution factor) with commutator short-circuited

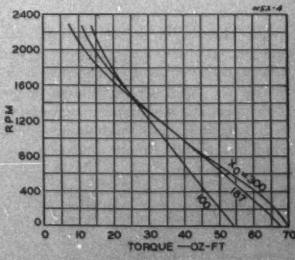

Figure 4. Effect of X_a, the "open-circuit reactance"

Kw_{21} = rotor winding factor operating repulsion

Kw_3 = winding factor of short-circuited coils

A_b = brush area (minus mica area) in square inches

Equation 1 gives the value of rotor resistance r_{21} to be used for calculation when the motor is operating as an induction motor with all the commutator bars short-circuited. Equation 2 should be used for the rotor resistance r_2 when operating repulsion, and equation 3 should be used for r_3. It can be shown that for uniform coil rotors, Kw_{21} and Kw_{23} are equal, and it may then be noted that when the brush resistance is equal to zero, r_{21} equals r_3. It is, therefore, convenient to obtain the ralue r_3 from the formula given below.

$$r_{3\ \text{repulsion}} = r_{21\ \text{induction}} \frac{R_A+R_B}{R_A} \qquad (4)$$

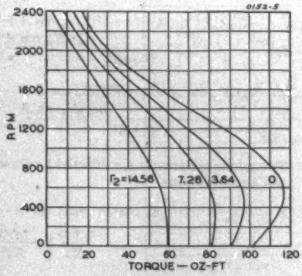

Figure 5. Effect of rotor resistance

where

$$R_A = \frac{r_c N_c}{a} \text{ and } R_B = \frac{r_b A}{A_b}$$

The value for r_3 may be obtained in a similar manner.

$$r_3 = r_{21}\left[\left(\frac{r_c+R_B}{r_c}\right)\frac{N_c}{a}\frac{DF_{21}}{DF_3}\right] \qquad (5)$$

where

DF_{21} = distribution factor when operating induction (approximately 0.637)

DF_3 = distribution factor for short-circuited coils (usually 1.0)

Figure 10 shows the effect of current density on the brush resistance. To be exact, it would be necessary to use a different value of r_3 corresponding to the current density, for each point of a calculated speed-torque curve. In practice, r_3 is usually high enough so that an average value may be used for the whole

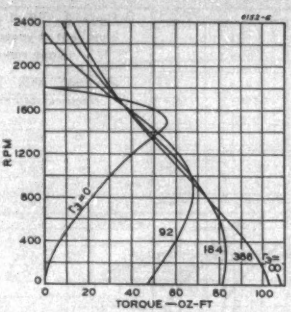

Figure 6. Effect of brush short-circuit resistance

curve. It will be found that the brush current densities for most repulsion-start induction-run motors are very high reaching several hundred amperes per square inch during the starting period.

Conclusions and Acknowledgments

The derivation of the equations of the calculation sheet is given in appendix I along with an example illustrating its use. Derivations relating to the motor constants and brush resistances are given in appendix II.

The brush resistance curve of figure 10 is from data furnished by the National Carbon Company.

Partial List of Symbols

(All secondary values are referred to the primary.)

E = applied voltage

I_1 = line or primary current

I_2 = secondary current in main field

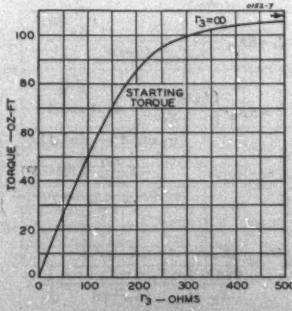

Figure 7. Effect of brush short-circuit resistance on starting torque

I_3 = secondary current in cross field (brush short-circuit current)

r_1 = primary resistance

r_{21} = rotor resistance as induction motor

r_2 = resistance of main field-rotor circuit

r_3 = resistance of cross-field rotor circuit (brush short-circuit resistance)

X_m = mutual or magnetizing reactance of stator and rotor windings

x_1 = leakage reactance of primary

x_2 = leakage reactance of each rotor circuit

f = frequency

S = speed as a fraction of synchronism

A = angle of brush shift in electrical degrees

Φ_t = flux in transformer axis (main field)

Φ_f = flux in field axis (cross field)

Appendix I

Derivation of Repulsion Motor Performance Equations

The circuits of a repulsion motor may be represented schematically by the diagram of figure 1. If A is the angle of brush shift in electrical degrees, the equations for the three circuits may be set up according to Kirchhoff's law. Mr. West[1] writes these equations as given below:

$$E = jX_m(I_1\cos^2 A - I_3\cos A) + jX_m(I_1\sin^2 A - I_3\sin A) + (r_1+jx_1)I_1$$

$$0 = -jX_m(I_1\cos A - I_3) + (r_3+jx_2)I_2 + SX_mI_1\sin A - S(X_m+x_2)I_2$$

$$0 = -jX_m(I_1\sin A - I_3) + (r_3+jx_2)I_3 - SX_m(I_1\cos A - I_3) + Sx_2I_2$$

Solving these equations for the three currents,

$$I_1 = E\times\frac{[r_2r_3-(1-S^2)(X_m+x_2)^2+j(r_3+r_2)(X_m+x_2)]}{U'+jW'}$$

$$I_2 = EX_m\times\frac{[-Sr_3\sin A-(1-S^2)(X_m+x_2)\cos A+jr_3\cos A]}{U'+jW'}$$

$$I_3 = EX_m\times\frac{[Sr_2\cos A-(1-S^2)(X_m+x_2)\sin A+jr_2\sin A]}{U'+jW'}$$

where

$$U' = -r_2X_m^2\cos^2 A - r_2X_m^2\sin^2 A - (r_2+r_3)(x_1+x_2)X_m - (r_2+r_3)x_1x_2 + r_1r_2r_3 - (1-S^2)r_1(X_m+x_2)^2$$

$$W' = r_1(r_2+r_3)(X_m+x_2) + r_2r_3(X_m+x_1) + S(r_3-r_2)X_m^2\sin A\cos A - (1-S^2)\times(X_m+x_2)[X_m(x_1+x_2)+x_1x_2]$$

Torque in synchronous watts =

$$\frac{E^2X_m^2}{U'^2+W'^2}\left\{(r_2^2-r_3^2)(X_m+x_2)\sin A\cos A + (r_2\sin^2 A + r_3\cos^2 A)[-Sr_2r_3 + S(1-S^2)\times(X_m+x_2)^2]\right\}$$

It is advisable, at this point, to divide the numerator and denominator of the current equations by $(X_m+x_2)^2$ and the torque equation by $(X_m+x_2)^4$.

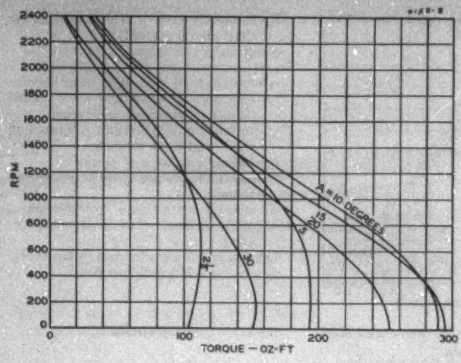

Figure 8. Effect of brush shift on speed-torque curves

A = Brush shift in electrical degrees

Then

$$I_1 = E\frac{\frac{r_2 r_3}{(X_m+x_3)^2}-\frac{(1-S^2)(X_m+x_2)^2}{(X_m+x_3)^2}+j\frac{(r_2+r_3)(X_m+x_2)}{(X_m+x_3)^2}}{U+jW}$$

$$I_2 = \frac{EX_m}{(X_m+x_3)}\frac{\frac{-Sr_2\sin A}{X_m+x_2}-(1-S^2)\frac{X_m+x_3}{X_m+x_2}\times\cos A+j\frac{r_3}{X_m+x_3}\cos A}{U+jW}$$

$$I_3 = \frac{EX_m}{(X_m+x_3)}\frac{\frac{Sr_2}{X_m+x_2}\cos A-(1-S^2)\times\frac{X_m+x_2}{X_m+x_3}\sin A+j\frac{r_2}{X_m+x_3}\sin A}{U+jW}$$

$$T=\frac{\frac{E^2X_m^2}{(X_m+x_3)^2}}{U^2+W^2}\left\{\frac{(r_2^2-r_3S^2)(X_m+x_3)}{(X_m+x_3)^3}\times\sin A\cos A+[r_2\sin^2 A+r_3\cos^2 A]\times\left[-S\frac{r_2r_3}{(X_m+x_3)^2}+S(1-S^2)\frac{(X_m+x_2)^2}{(X_m+x_3)^2}\right]\right\}$$

where

$$U=-r_3\frac{X_m^2}{(X_m+x_3)^2}\cos^2 A-r_2\frac{X_m^2}{(X_m+x_3)^2}\times\sin^2 A-\frac{(r_2+r_3)(x_1+x_3)X_m}{(X_m+x_3)^2}+\frac{(r_2+r_3)x_3x_2}{(X_m+x_3)^2}+\frac{r_1r_2r_3}{(X_m+x_3)^2}-(1-S^2)r_1\frac{(X_m+x_3)^2}{(X_m+x_3)^2}$$

$$W=\frac{r_1(r_3+r_3)(X_m+x_3)}{(X_m+x_3)^2}+\frac{r_2r_3(X_m+x_1)}{(X_m+x_3)^2}+\frac{S(r_2+r_3)X_m^2\sin A\cos A}{(X_m+x_3)^2}-(1-S^2)\times\frac{(X_m+x_3)}{(X_m+x_3)^2}[X_m(x_1+x_2)+x_1x_2]$$

$$\Phi_f=\frac{\sqrt{2}I_3(X_m+x_3)}{2\pi fN10^{-8}}\left[\frac{X_m}{(X_m+x_3)}\frac{I_1}{I_3}\sin A-1\right]$$

$$\Phi_t=\frac{\sqrt{2}I_3(X_m+x_3)}{2\pi fN10^{-8}}\left[\frac{X_m}{(X_m+x_3)}\frac{I_1}{I_3}\cos A-1\right]$$

From this point on, we will depart from Mr. West's derivation, and method of attack. For simplicity of calculation, and so that the designer may know just how the motor losses are distributed, we will calculate the magnitudes alone of the currents, and obtain the input from the sum of output and losses. In order to simplify the above equations, let us arbitrarily define

$$X_3 = X_m + x_3$$

$$K_p = \frac{X_m}{X_m+x_3} = \frac{X_m}{X_3}$$

$$K_r = K_p^2 = \frac{X_m^2}{X_3^2} = \frac{X_m^2}{(X_m+x_3)^2}$$

$$I_1 = E\frac{\frac{r_2}{X_3}\frac{r_3}{X_3}-(1-S^2)+j\frac{(r_2+r_3)}{X_3}}{U+jW}$$

$$I_2 = EK_p\frac{-S\frac{r_2}{X_3}\sin A-(1-S^2)\cos A+j\frac{r_2}{X_3}\cos A}{U+jW}$$

$$I_3 = EK_p\frac{S\frac{r_2}{X_3}\cos A-(1-S^2)\sin A+j\frac{r_2}{X_3}\sin A}{U+jW}$$

$$T=\overline{EK_p}^2\left\{\frac{\frac{(\sqrt{r_2^2-r_3^2})^2}{X_3}\sin A\cos A+[r_2\sin^2 A+r_3\cos^2 A]\times\left[-S\frac{r_2r_3}{X_3X_3}+S(1-S^2)\right]}{U^2+W^2}\right\}$$

$$U=-r_2K_r\cos^2 A-r_3K_r\sin^2 A-\frac{(r_2+r_3}{X_3}\left[\frac{x_1X_m+x_2X_m+x_1x_2}{(X_m+x_3)}\right]+\frac{r_1r_2r_3}{X_3X_3}-(1-S^2)r_1$$

$$W=\frac{r_1(r_2+r_3)}{X_3}+\frac{r_2r_3}{X_3}\frac{(X_m+x_1)}{(X_m+x_3)}+S(r_2-r_3)K_r\sin A\cos A-(1-S^2)\left[\frac{x_1X_m+x_2X_m+x_1x_2}{X_m+x_3}\right]$$

$$\Phi_{f\max}=I_3X_3\left(\frac{I_1}{I_3}K_p\sin A-1\right)\frac{45\times10^8}{fCK_w}$$

$$\Phi_{t\max}=I_3X_3\left(\frac{I_1}{I_3}K_p\cos A-1\right)\frac{45\times10^8}{fCK_w}$$

(It must be remembered that the currents are vectors in these equations.)

Let us now define

$$i_m=\frac{E}{X_3}$$

$$X=x_1+x_2K_p=\frac{x_1X_m+x_2X_m+x_1x_2}{X_m+x_3}$$

Then

$$I_1=\frac{i_mr_3\frac{r_2}{X_3}-E(1-S^2)+ji_m(r_2+r_3)}{U+jW}$$

$$I_2=\frac{-Si_mr_3K_p\sin A-(1-S^2)EK_p\cos A+ji_mr_2K_p\cos A}{U+jW}$$

$$I_3=\frac{Si_mr_3K_p\cos A-(1-S^2)EK_p\sin A+ji_mr_3K_p\sin A}{U+jW}$$

The torque equation is not affected by these last simplifications.

$$U=-(1-S^2)r_1-r_2K_r\cos^2 A-r_3K_r\sin^2 A-\frac{r_2+r_3}{X_3}X+\frac{r_1r_2r_3}{X_3^2}$$

$$W=-(1-S^2)X+S(r_2-r_3)K_r\sin A\cos A+r_1\frac{r_2+r_3}{X_3}+\frac{r_2r_3(X_m+x_1)}{X_3(X_m+x_3)}$$

In motors of normal proportions, r_3 is very large, and often as a check, a calculation is made with r_3 increased to infinity. This is a convenient way to tell whether the brush resistance is as large as it ought to be. Let us divide both numerator and denominator of the current equations by $-r_3$ and the torque equation by $(-r_3)^2$. This will cause the terms affected by the useless brush short-circuit current, to become smaller and smaller as r_3 approaches infinity.

$$U=(1-S^2)\frac{r_1}{r_2}+\frac{r_2}{r_2}K_r\cos^2 A+K_r\sin^2 A+\frac{X}{X_3}\left(1+\frac{r_2}{r_3}\right)-\frac{r_1r_2}{X_3X_3}$$

$$W=(1-S^2)\frac{X}{r_3}-S\left(1-\frac{r_2}{r_3}\right)K_r\sin A\cos A-\frac{r_1}{X_3}\left(1+\frac{r_2}{r_3}\right)-\frac{r_2}{X_3}\frac{(X_m+x_1)}{(X_m+x_3)}$$

$$I_1=\frac{(1-S^2)\frac{E}{r_3}-\frac{i_mr_2}{X_3}-ji_m\left(1+\frac{r_2}{r_3}\right)}{U+jW}$$

Figure 12. Calculation sheet for repulsion motors

	E	220	X_o	62.8	1	S = RPM/SYN	0	.1	.25	.50	.75	1.00	1.25
	X	5.48	L_m	3.50	2.	S^2	0	.01	.0625	.25	.561	1.00	1.563
	K_P	.955	K_T	.914	3	$(1-S^2)$	1.00	.99	.938	.75	.439	0	-.563
	r_1 HOT	1.10	r_2 HOT	2.70	4	③ × r_1/r_3	.0110	.0109	.0103	.0083	.0048	0	-.0062
	BRUSH	3/16	x 3/4		5	H_8	.1814	.1814	.1814	.1814	.1814	.1814	.1814
	N_C	64	A_B	.1166	6	U = (4) + (5)	.1924	.1923	.1917	.1897	.1862	.1814	.1752
	a	4	r_B	.009	7	③ × X/r_2	.0548	.0543	.0515	.0411	.0241	0	-.0309
			$(r_{B1}/r_{B2})^2$	.406	8	SH_3	0	.0221	.0583	.1105	.1653	.211	.276
	$K_A = \frac{r_2 N_C}{a}$	1.044	r_C HOT	.0653	9	⑦ − ⑧	.0548	.0322	-.0038	-.0694	-.1417	-.211	-.3469
	$K_B = \frac{r_B N_C}{a}$	.308	R_B	.308	10	H_1	.0738	.0738	.0738	.0738	.0738	.0738	.0738
	$R_A + R_B$	1.352	$r_C + R_B$	.3733	11	W = ⑤ − ⑩	-.0190	-.0416	-.0776	-.1432	-.2135	-.295	-.3691
	$r_2 - r_{B1} \frac{N_C}{a}$	3.50	r_3	100.	12	$\sqrt{U^2 + W^2}$	.143	.147	.207	.238	.285	.346	.419
	r_2/X_o	.0557	r_2/r_3	.035	13	⑨ = E/r_3	2.20	2.18	2.06	1.65	965	0	-1.24
	X/X_o	.0872	$1 + r_1/r_3$	1.035	14	H_4	.195	.195	.195	.195	.195	.195	.195
	r_1/X_o	.0175	$1 - r_2/r_3$	.965	15	(13) − (14)	2.005	1.985	1.865	1.455	.770	-.195	-1.435
	r_1/r_3	.011	X/r_3	.0548	16	$\sqrt{(13)^2 + H_8^2}$	4.14	4.13	4.08	3.91	3.70	3.63	3.89
					17	$I_1 = (16)/(12)$	21.5	21.0	19.7	16.4	13.0	10.5	9.28
					18	⑨ × H_{12}	2.03	2.01	1.905	1.523	.890	0	-1.143
A	BRUSH SHIFT			15°	19	SH_9	0	.087	.217	.433	.650	.866	1.083
	SIN A			.259	20	(18) + (19)	2.03	2.10	2.122	1.956	1.540	.866	-.060
	COS A			.966	21	$\sqrt{(20)^2 + H_8^2}$	3.82	3.85	3.87	3.78	3.58	3.34	3.33
C	SIN A COS A			.250	22	$I_2 = (21)/(12)$	19.8	19.6	18.7	16.9	12.56	9.65	7.71
	$(r_2/r_3)\cos^2 A$			.0327	23	⑨ × H_{13}	.554	.549	.520	.416	.244	0	-.312
	$\sin^2 A$			.0671	24	SH_5	0	.0113	.0283	.0565	.0847	.113	.141
B	$(r_2/r_3)\cos^2 A + \sin^2 A$			.0998	25	(22) − (24)	.554	.538	.492	.359	.159	-.113	-.453
	$(r_1/X_o)(1 + r_2/r_3)$			.0181	26	$\sqrt{(23)^2 + H_8^2}$	.554	.530	.492	.360	.162	.117	.454
	r_2/X_o			.0557	27	$I_3 = (26)/(12)$	2.83	2.73	2.38	1.51	.568	.338	1.083
H_1	$(r_2/X_o)(1 + r_2/r_3) + r_2/X_o$			.0738	28	⑨ × H_{14}	—	43.6	41.3	33.0	19.3	0	-24.8
	$\frac{X}{X_o}(1 + r_2/r_3)$			.0902	29	H_7	—	3.9	3.9	3.9	3.9	3.9	3.9
	$K_T B$			.0912	30	(28) − (29)	—	39.7	37.4	29.1	15.4	-3.9	-28.7
H_2	$\frac{X}{X_o}(1 + r_2/r_3) + K_T B$			.1814	31	S × (30)	0	3.97	9.35	14.56	11.56	-3.9	-35.9
H_3	$K_T C(1 - r_2/r_3)$			.221	32	H_{11}	175.8	175.8	175.8	175.8	175.8	175.8	175.8
H_{10}	$L_m(1 + r_2/r_3)$			3.62	33	(31) + (32)	175.8	179.8	185.2	190.4	187.4	171.9	139.9
H_{11}	E H_3 H_{10}			175.8	34	$(38/(12))^2$	4720	4640	4320	3360	2300	1435	796
H_{14}	$(EK_A)^2 B/r_3$			44.0	35	F_e + F&W	0	1.	7	27	62	110	172
H_7	$(L_m^2 r_2)(K_T B)$			3.92	36	SYN. WATTS = (34) − (35)	4720	4639	4313	3333	2238	1325	624
H_8	$L_m K_P \cos A$			3.23	37	RPM = S × SYN	0	180	450	900	1350	1800	2250
H_5	$H_8 r_2/r_3$			.113	38	TORQUE = $\frac{11.2}{SYN}$ × (36)	295	291	270	209	140	83	39
H_9	$L_m K_P \sin A$			.866	39	OUTPUT = S × (36)	0	464	1079	1667	1680	1325	780
H_6	$H_9 r_2/r_3$			.0303	40	PRIM. LOSS = $I_1^2 r_1$	507	486	428	297	186	121	95
H_{12}	$(E/r_3) K_P \cos A$			2.03	41	SEC. $LOSS_m = I_2^2 r_2$	1370	1340	1225	883	552	327	208
H_{13}	$(E/r_3) K_P \sin A$			.554	42	SEC. $LOSS_C = I_3^2 r_C$	825	749	564	229	32	11	117
H_4	$L_m r_2/X_o$			.195	43	TOT. LOSS = (39)+(40)+(41)+(42)	2702	2576	2234	1486	832	579	592
					44	INPUT = (39) + (43)	2702	3040	3313	3103	2512	1904	1372
					45	EFF. = (44)/(44)	0	15.3	32.5	53.7	66.9	69.5	56.8
					46	P.F. = (44)/EI$_1$	57.2	65.8	76.4	87.6	87.8	82.3	67.2
					47	H.P. OUTPUT	0	.611	1.446	2.23	2.25	1.776	1.046
					48								
					49								
					50								
					51								
					52								

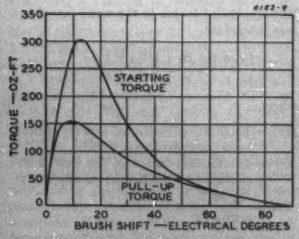

Figure 9. Effect of brush shift on starting and pull-up torques

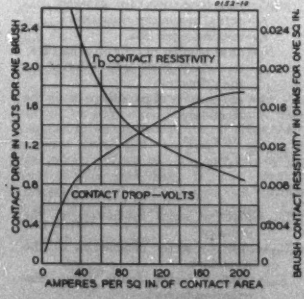
0152-10
r_b CONTACT RESISTIVITY
CONTACT DROP—VOLTS
CONTACT DROP IN VOLTS FOR ONE BRUSH
BRUSH CONTACT RESISTIVITY IN OHMS FOR ONE SQ IN.
AMPERES PER SQ IN. OF CONTACT AREA

Figure 10. Typical brush resistance and volt-ampere curves

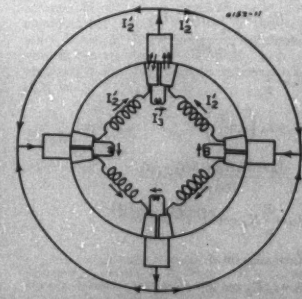

Figure 11. Schematic diagram of secondary circuit of repulsion motor

$$I_3 = \frac{(1-S^2)\frac{E}{r_3}K_p \cos A + Si_m K_p \sin A - ji_m K_p \cos A}{U+jW}$$

$$I_4 = \frac{(1-S^2)\frac{E}{r_3}K_p \sin A - Si_m \frac{r_2}{r_3}K_p \cos A - ji_m \frac{r_2}{r_3}K_p \sin A}{U+jW}$$

$$T = \frac{S\left\{(1-S^2)\left[\frac{EK_p}{r_3}^2\left(\frac{r_2}{r_3}\cos^2 A + \sin^2 A\right)\right] - \left(\frac{EK_p}{X_0}\right)^2 r_3\left(\frac{r_2}{r_3}\cos^2 A + \sin^2 A\right)\right\}}{U^2+W^2} + \frac{\frac{EK_p}{X_0}^2 \sin A \cos A\left[1-\left(\frac{r_2}{r_3}\right)^2\right]}{U^2+W^2}$$

For purposes of calculation, let us arrange the terms in each equation into groups, those terms which are a function of speed in one group, and those which are independent of speed in another group.

$$U = (1-S^2)\frac{r_1}{r_3} + H_2$$

where

$$H_2 = K_r B + \frac{X}{X_0}\left(1+\frac{r_1}{r_3}\right) - \frac{r_1 r_3}{X_0 X_0}$$

(This last term $\frac{r_1 r_3}{X_0 X_0}$ is usually negligible)

$$B = \frac{r_3}{r_3}\cos^2 A + \sin^2 A$$

$$W = (1-S^2)\frac{X}{r_3} - SH - H_1$$

$$H_3 = K_r\left(1-\frac{r_2}{r_3}\right)C$$

$$C = \sin A \cos A$$

$$H_1 = \frac{r_1}{X_0}\left(1+\frac{r_2}{r_3}\right) + \frac{r_2}{X_0}\frac{(X_m+x_1)}{(X_m+x_2)}$$

(The term $\frac{(X_m+x_1)}{(X_m+x_2)}$ can usually be taken as unity)

$$I_1 = \frac{(1-S^2)\frac{E}{r_3} - H_4 - jH_{10}}{U+jW}$$

$$H_4 = \frac{i_m r_2}{X_0}$$

$$H_{10} = i_m\left(1+\frac{r_2}{r_3}\right)$$

$$I_2 = \frac{(1-S^2)H_{12} + SH_3 - jH_5}{U+jW}$$

$$H_{12} = \frac{E}{r_3}K_p \cos A$$

$$H_3 = i_m K_p \sin A$$

$$H_5 = i_m K_p \cos A$$

$$I_3 = \frac{(1-S^2)H_{13} - SH_5 - jH_6}{U+jW}$$

$$H_{13} = \frac{E}{r_3}K_p \sin A$$

$$H_5 = i_m \frac{r_2}{r_3}K_p \cos A$$

$$H_6 = i_m \frac{r_2}{r_3}K_p \sin A$$

Torque in synchronous watts $= \frac{S[(1-S^2)H_{14} - H_7] + H_{11}}{U^2+W^2}$

$$H_7 = i_m^2 r_3 K, B$$

$$H_{11} = EH_{10}H_3$$

$$H_{14} = \overline{EK_p}^2 \frac{B}{r_3}$$

Output $= S$ times torque in synchronous watts

Torque in ounce-feet $= \frac{112.7}{\text{synchronous rpm}}$ times torque in synchronous watts

By arranging the calculation of these terms in proper sequence, a simple and straightforward calculation sheet may be obtained. Such a calculation sheet is shown in figure 12.

Appendix II

Derivation of the Equations of Rotor Resistance

The secondary resistance of the armature of a repulsion motor must be calculated for two separate conditions when operating repulsion, and for a third condition when operating induction in a repulsion-start, induction-run motor. In all cases, the problem is to obtain the effective secondary resistance, referred to the primary, of a motor which for this problem may be considered as a transformer. Since the resistances of a transformer may be transferred from primary to secondary or vice versa by multiplying by the square of the transformation ratio, the problem becomes one of correctly determining the actual secondary resistance, and the transformation ratio.

Let

"ratio" = transformation ratio squared
r_3 = actual secondary resistance
r_c = resistance per coil
N_c = total number of coils on armature
r_3 = secondary resistance referred to the primary
a = the number of parallel paths in the secondary

$$\text{"ratio"} = \frac{(CK_{wm})^2}{(CK_{ws})^2}$$

where

CK_{wm} = effective series conductors of the primary
CK_{ws} = effective series conductors of the secondary
K_w = winding factor (pitch times distribution factor)

Then

r_3 = "ratio" times r_c

CASE I

Repulsion-start, induction-run motor operating induction with all bars of the commutator short-circuited.

$r_{3i} = r_c / N_c$

$CK_{wi} = 2\,tpc\,K_{wsi}$ (K_{wsi} is usually close to 0.637)

tpc = turns per coil on the armature

CASE II

Normal repulsion motor, r_3 = resistance of main phase or useful part of the armature.

$$r_{3i} = \frac{r_c N_c}{a} + \frac{r_b A}{A_b}$$

where

N_c/a = number of coils between brushes
r_b = resistance per square inch of brush contact
A_b = brush contact area in square inches (minus that area of the brush in contact with mica)

$CK_{wsi} = \frac{2\,tpc\,N_c K_{wsi}}{a}$ (K_{wsi} is usually close to 0.637)

It can be shown that if r_b equal zero, $r_M = r_{3i}$. Thus

$$r_3 = r_{3i}\frac{R_A + R_B}{R_A}$$

Where

$$R_A = \frac{r_c N_c}{a} \text{ and } R_B = \frac{r_b A}{A_b}$$

CASE III

Normal repulsion motor, r_3 = secondary resistance of the short-circuited coils.

$$r_{3i} = \frac{r_c + \frac{r_b A}{A_b}}{a}$$

$CK_{ws} = 2\,tpc\,K_{ws}$ (K_{ws} is usually equal to the armature chord factor, for with the brush spanning two bars only, and the one coil connected to these bars in one slot only, the distribution factor will be unity)

A convenient method calculating r_3 is to write the formula in terms of r_M

$$r_3 = r_{3i}\frac{(K_{wsi})^2}{(K_{ws})^2}\frac{r_c + R_B}{r_c}\frac{N_c}{a}$$

But the chord factor is the same for either case, therefore

$$r_3 = r_{3i}\left\{\frac{r_c + R_B}{r_c}\frac{N_c}{a}\left[\frac{DF_M}{DF_3}\right]^2\right\}$$

where

DF_M = distribution factor of short-circuited rotor, usually about 0.637
DF_3 = distribution factor of the coil short-circuited by the brush, usually unity

$$DF = \frac{\sin n\theta/2}{n \sin \theta/2}$$

where

n = number of coils
θ = angle between coils in electrical degrees

Performance Calculations on Capacitor Motors

The Revolving-Field Theory

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MEMBER AIEE

Synopsis: A method is presented whereby the equations of capacitor motor performance calculation as developed by Mr. W. J. Morrill,[1] are arranged in a calculation sheet or form for use in routine design work.

IN 1929, W. J. Morrill presented his classic paper on "The Revolving Field Theory of the Capacitor Motor", giving the complete equations for calculating the performance and torque of a capacitor motor at any value of slip.

The equations are straightforward, but involve vector operations, and are rather slow for routine design work. Since 1929, many engineers have used the method, and have devised different methods of doing the many numerical operations necessary to obtain a final solution. The methods have varied from one extreme to the other, some engineers using the equations directly as written making each vector operation as necessary, and others working up a calculation sheet where all operations were numerical.

Although engineers as a rule are perfectly capable of handling vector operations, most of those involved in motor design work, feel that any great number of vector operations in the midst of routine work, brings considerable risk of errors, and they like to avoid vectors where possible. The writer has developed a calculation sheet for using these formulas, where all the operations except the last in calculating the currents are performed without vectors. This seems to be a fairly satisfactory compromise between the difficulties of either extreme, and has worked out quite well in practice.

Calculation Sheet for Mr. Morrill's Equations

Figures 1 and 2 show pages 1 and 2 of the calculation method. As in Mr. Morrill's paper, the method consists of determining the currents in each branch circuit and their angles with the voltage. With these values, the torque, output, and losses may be determined. Figure 1 is taken up with the calculation of currents, and figure 2 with calculation of torque and performance. The first part of figure 1 covers the calculation of the apparent resistance and reactance of the secondary circuit to the forward and backward fields.

It will be noted that many of the terms and expressions in the equations are of very similar form. Advantage has been taken of this to arrange the sheet so that the operations are performed in two columns in such a way that the numbering of the operations is nearly the same. That is, operations 1, 2, 3, 4, etc. are exactly the same in form as operations 101, 102, 103, and 104. Upon reaching operation 13 and 113, it becomes necessary to cross from one column to the other occasionally, but the same essential similarity between the two columns is kept.

Iron Loss

A slightly different method of accounting for iron loss is used than that of Mr. Morrill. Mr. Morrill's equations neglect iron loss and then correct for it by adding it to the friction and windage losses as a reduction in output.

The writer has found that a closer comparison between calculated values and tested values may be obtained, if a slightly different method of iron loss correction is used. As with Mr. Morrill, the vector operations of items 35, and 37 give fictitious values of current which have been obtained while neglecting iron loss entirely. These fictitious values are used in calculating the internal torque and output. The friction, windage, and odd-frequency iron losses are then sub-

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Brush Contact Resistance

The equations for secondary resistance contain a term which is a function of the contact drop at the brush and commutator. The resistance of the contact is determined by a number of things. First, the type of brush, second the current density, and in addition to these factors it is affected by the speed and temperature of the commutator. A typical brush resistance curve as a function of current density is shown in figure 10. It is furnished through the courtesy of the National Carbon Company. It will be noted that the curve has been extended beyond the conditions of normal continuous operation. This is done because motors designed for repulsion operation during the starting period only, have small brushes, and abnormally high current densities. These densities are likely to be between 100 and 300 amperes per square inch at the standstill condition.

As mentioned above, in order to be exact, it would be necessary to use a different value of brush resistance for each point of a calculated speed-torque curve. However, for practical cases, it is usually sufficiently accurate, to use the starting current density throughout the entire range of the caclulation.

Actual Secondary Currents

Figure 11 illustrates the conditions occurring at the brush, with the useful currents entering the brush from adjacent commutator bars, and the short-circuit current entering from one bar and leaving by way of the next bar. It may happen in some cases, that the short-circuit current is even greater than the useful current. For convenience, the actual values of the currents are given below.

$$I_1' = I_1 \frac{CK_{wm}}{CK_{wt}} \frac{1}{a}$$

$$I_1' = I_1 \frac{CK_{wm}}{CK_{wt}} \frac{1}{a}$$

Reactance Voltage

Since r_b is so much greater than the reactance of the short-circuited coils, the commutation voltage referred to the primary is simply I_{sf_b}. However, the actual voltage commutated by the brush must be obtained from the transformation ratio, that is,

$$E_c = I_{sf_b} \frac{2\pi p c K_{wsf} a}{CK_{wm}}$$

Bibliography

1. THE CROSS-FIELD THEORY OF ALTERNATING-CURRENT MACHINES, H. R. West. AIEE TRANSACTIONS, February 1926, page 466.

2. PERFORMANCE CALCULATIONS ON INDUCTION MOTORS, C. G. Veinott. AIEE TRANSACTIONS, September 1932, page 743.

| | | |

tracted to give the useful output. A close approximation to the true current is obtained by adding to the in-phase component of the main winding current a value of in-phase current obtained by dividing the fundamental-frequency iron loss by the voltage.

This method accounting for the iron loss is based on the fact that the fundamental-frequency iron losses are normally supplied by the stator and the odd-frequency losses of the surfaces and tooth pulsations are supplied by the rotating member with a corresponding loss of torque.

Performance Calculation

Credit should be given to C. G. Veinott of the Westinghouse Electric and Manufacturing Company for the essential form of figure 2. It should be noted that the fictitious values of the currents are used for calculating the torque and the corrected values for calculating the stator copper losses. The odd-frequency iron losses are subtracted from the gross output along with the friction and windage.

It is believed that more accuracy is secured by obtaining the input from the output plus losses rather than by multiplying the voltage and the in-phase component of the line current. However, it is usually wise to check the two methods against each other.

Appendix

It is well at this point to definitely state the object of the following derivations. It is simply this: Starting with Mr. Morrill's equations, the object is to develop a simple routine calculation form which will give the performance of a capacitor motor at any speed when the necessary impedances or motor constants are known. The desired form is one with which results of practical accuracy are obtained with a minimum amount of calculation time, and the least likelihood of errors. From the point of view of routine work, it is also desirable that the work may be easily resumed after interruptions such as telephone calls, interviews, etc.

Since the design engineer who works on single-phase motors is very likely to design split-phase, capacitor-start, repulsion, and capacitor-run motors, the symbols and form of the calculation sheet have been arranged in accordance with the single-phase performance method of C. G. Veinott[3] and with the repulsion motor method of the writer now in process of publication by the AIEE.

The three fundamental equations of Mr. Morrill are as follows:

$$I_s = E_m \left\{ \frac{[(R_{1m}+R_f+R_b)+j(X_{1m}+X_f+X_b)]-ja[(R_f-R_b)+j(X_f-X_b)]}{\begin{matrix}[(R_c+a^2(R_{1a}+R_f+R_b)]+j[X_c+a^2(X_{1a}+X_f+X_b)]] \\ [(R_{1m}+R_f+R_b)+j(X_{1m}+X_f+X_b)]-a^2[(R_f-R_b)+j(X_f-X_b)]^2\end{matrix}} \right\} \quad (123)$$

$$\text{Torque(average)} = [I_m^2+a^2I_s^2][R_f-R_b]+2a[Ah-Bg][R_f+R_b] \quad (8)$$

where

$I_m = A+jB$ and $I_s = g+jh$

The rearrangement consists of the steps:

A. Rewriting the equations in the symbols of Mr. Veinott's paper.

B. Rewriting the equations for the forward and backward impedances.

C. Obtaining the current terms $A+jB$ and $g+jh$ in quotient form.

$$A+jB = \frac{(26)+j(126)}{(33)+j(133)}$$

and

$$g+jh = \frac{(20)+j(120)}{(33)+j(133)}$$

D. Rearranging the torque equation so that the components $(26)+j(126)$ and $(20)+j(120)$ may be used instead of $A+jB$ and $g+jh$. This allows the calculation of torque without any vector operations.

E. Adding an in-phase iron loss component to $A+jB$ to correct for stator iron loss.

F. Addition of phase currents to obtain the line current.

A. Rewriting the Equations in the Symbols of Mr. Veinott's Paper. (See Table I)

Let us arbitrarily define

$$X_0 = X_m+x_2, \quad K_p = X_m/(X_m+x_2), \quad K_r = K_p^2 = X_m^2/X_0^2$$

Substitute these values and divide both numerator and denominator by $X_0^2/4$

$$R_f = \frac{1}{2}\,\frac{(r_2K_r)1/s}{[(r_2/X_0)(1/s)]^2+1}$$

R_b becomes the same equation with $(2-s)$ in place of s

$$R_b = \frac{1}{2}\,\frac{(r_2K_r)\,1/(2-s)}{[(r_2/X_0)(1/(2-s))]^2+1}$$

Mr. Morrill writes

$$X_f = \frac{X_m[(R_2/s)^2+X_2(X_2+X_m)]}{(R_2/s)^2+(X_2+X_m)^2} =$$

Rewritten in symbols of Mr. Veinott

$$\frac{(X_m/2)[(r_2/2s)^2+x_2(x_2+X_m)/4]}{(r_2/2s)^2+(x_2+X_m)^2/4}$$

Table I

New Symbol	Old Symbol	Definition
K	e	Total effective series conductors in auxiliary phase / Total effective series conductors in main phase
r_{1a}	a^2R_{1a}	Primary resistance of auxiliary phase
x_{1a}	a^2X_{1a}	Primary leakage reactance of auxiliary phase
r_{1m}	R_{1m}	Primary resistance of main phase
r_2	$2R_2$	Total secondary resistance referred to primary of main phase
x_{1m}	X_{1m}	Primary leakage reactance of main phase
x_2	$2X_2$	Total secondary leakage reactance referred to primary of main phase
X_m	$2X_m$	Total magnetizing reactance of main phase
s	S	Slip in per unit of synchronism
I_a	I_s	Auxiliary phase current

$$I_m = E_m \left\{ \frac{[R_c+r_{1a}+K^2(R_f+R_b)]+j[X_c+x_{1a}+K^2(X_f+X_b)]+jK[(R_f-R_b)+j(X_f-X_b)]}{\begin{matrix}[[R_c+r_{1a}+K^2(R_f+R_b)]+j[X_c+x_{1a}+K^2(X_f+X_b)]] \\ [(r_{1m}+R_f+R_b)+j(x_{1m}+X_f+X_b)]-K^2[(R_f-R_b)+j(X_f-X_b)]^2\end{matrix}} \right\}$$

$$I_a = E_m \left\{ \frac{[(r_{1m}+R_f+R_b)+j(x_{1m}+X_f+X_b)]-jK[(R_f-R_b)+j(X_f-X_b)]}{\begin{matrix}[[R_c+r_{1a}+K^2(R_f+R_b)]+j[X_c+x_{1a}+K^2(X_f+X_b)]] \\ [(r_{1m}+R_f+R_b)+j(x_{1m}+X_f+X_b)]-K^2[(R_f-R_b)+j(X_f-X_b)]^2\end{matrix}} \right\}$$

$$T_{avg} = (I_m^2+K^2I_a^2)(R_f-R_b)+2K(Ah-Bg)(R_f+R_b)$$

B. Rewriting the Forward and Backward Impedances

Mr. Morrill's equation

$$R_f = \frac{X_m^2\,R_2/s}{(R_2/s)^2+(X_2+X_m)^2} =$$

Rewritten in symbols of Mr. Veinott

$$\frac{(X_m/2)^2\,(r_2/2)(1/s)}{(r_2/2)^2(1/s)^2+\left(\dfrac{x_2+X_m}{2}\right)^2}$$

Substitute $X_0 = X_m+x_2$, $K_p = X_m/(X_m+x_2)$, divide both numerator and denominator by $X_0/4$, and rearrange

$$X_f = \frac{1}{2}\,\frac{x_2K_p+(r_2K_p)(r_2/X_0)(1/s)^2}{[(r_2/X_0)(1/s)]^2+1}$$

and

$$X_b = \frac{1}{2}\,\frac{x_2K_p+(r_2K_p)(r_2/X_0)(1/(2-s))^2}{[(r_2/X_0)(1/(2-s))]^2+1}$$

$$I_m = E_m \left\{ \frac{[R_c+a^2(R_{1a}+R_f+R_b)]+j[X_c+a^2(X_{1a}+X_f+X_b)]+ja[(R_f-R_b)+j(X_f-X_b)]}{\begin{matrix}[[R_c+a^2(R_{1a}+R_f+R_b)]+j[X_c+a^2(X_{1a}+X_f+X_b)]] \\ [(R_{1m}+R_f+R_b)+j(X_{1m}+X_f+X_b)]-a^2[(R_f-R_b)+j(X_f-X_b)]^2\end{matrix}} \right\} \quad (122)$$

C. Obtaining A+jB and g+jh in Quotient Form

It will be noted from the equations of I_m and I_a, that many of the groups of terms are the same. Let us rewrite them using a symbol for each group. For simplicity let us use for symbols the item numbers of the final calculation sheets figures 1 and 2. Our purpose is to obtain

$$A+jB=\frac{(26)+j(126)}{(33)+j(133)}$$

and

$$g+jh=\frac{(20)+j(120)}{(33)+j(133)}$$

Then, assigning a number symbol to each term, we obtain

$$A+jB=E_m\times\left\{\frac{(24)+j(124)+jK[(15)+j(115)]}{[(24)+j(124)]\{(18)+j(118)\}-K^2[(15)+j(115)]^2}\right\}$$

$$g+jh=E_m\times\left\{\frac{(18)+j(118)-jK[(15)+j(115)]}{[(24)+j(124)]\{(18)+j(118)\}-K^2[(15)+j(115)]^2}\right\}$$

Simplifying to obtain one real and one quadrature term in both numerator and denominator,

$$A+jB=E_m\times\left\{\frac{[(24)-K(115)]+j[(124)+K(15)]}{[(24)(18)-(124)(118)-K^2(15)^2+K^2(115)^2]+j[(18)(124)+(118)(24)-2(K15)(K115)]}\right\}$$

$$g+jh=E_m\times\left\{\frac{[(18)+K(115)]+j[(118)-K(15)]}{[(24)(18)-(124)(118)-K^2(15)^2+K^2(115)^2]+j[(18)(124)+(118)(24)-2(K15)(K115)]}\right\}$$

Assigning number symbols to the above groups of terms,

$$A+jB=E_m\frac{(26)+j(126)}{(32)+j(132)}$$

and

$$g+jh=E_m\frac{(20)+j(120)}{(32)+j(132)}$$

Dividing numerator and denominator by E_m gives the desired result

$$A+jB=\frac{(26)+j(126)}{(33)+j(133)}$$

and

$$g+jh=\frac{(20)+j(120)}{(33)+j(133)}$$

D. Rearranging the Torque Equation

$$T=(I_m^2+K^2I_a^2)(R_f-R_b)+2K(Ah-Bg)(R_f+R_b)$$

In order to avoid making the vector operation involved in obtaining A, B, g, and h, let

$$N_m=\sqrt{(26)^2+(126)^2}$$

$$N_a=\sqrt{(20)^2+(120)^2}$$

$$V=\sqrt{(33)^2+(133)^2}$$

Also since $(Ah-Bg)$ is the quadrature term obtained by multiplying $(g+jh)$ by the conjugate of $(A+jB)$, performing this operation on both right and left sides of the equations gives us an expression for $(Ah-Bg)$.

$$(A-jB)(g+jh)=(Ag+Bh)+j(Ah-Bg)$$

$$\frac{(26)-j(126)}{(33)+j(133)}\times\frac{(20)+j(120)}{(33)+j(133)}=\frac{[(26)(20)+(126)(120)]-j[(26)(120)-(126)(20)]}{(33)^2+(133)^2}$$

Thus

$$Ah-Bg=\frac{(26)(120)-(126)(20)}{V^2}$$

and

$$T=[(N_m/V)^2+(KN_a/V)^2](R_f-R_b)+2K\left[\frac{(26)(120)-(126)(20)}{V^2}\right](R_f+R_b)$$

This allows the calculation of torque without any vector operations, which is particularly desirable in calculating speed-torque curves, pull-up torque of capacitor-start motors, or in designing two- or three-speed fan motors.

E. Correcting for Primary Iron Loss

Although the fundamental frequency iron loss is supplied by the primary, and the odd-frequency iron loss by the rotor, it is not possible to include the stator iron loss in the primary part of the revolving field equations without making them too complicated. If the total iron loss is subtracted from the output similar to the friction and windage losses, it will be found in certain motors, particularly those designed for speed change driving low-horsepower fans, that the calculated useful torque will not agree with the tested value. The writer has had considerable success in approximating the true condition by simply adding an in-phase current component to the main phase current to account for the stator iron loss. This seems to agree with test much closer than adding half to the main phase and half to the auxiliary phase. The final main phase current is then

$$A+\frac{\text{fundamental-frequency iron loss}}{E_m}+jB$$

The auxiliary phase current is $g+jh$, and the line current is the vector sum.

In figure 1 the fundamental-frequency iron loss is denoted by the symbol "60 Cy Fe" and the odd-frequency iron loss by the symbol "Hi Cy Fe". $F+W$ is used as the symbol for friction and windage.

As a matter of interest, the motor used as an example for figure 1 is a one-fourth horsepower 230-volt 60-cycle six-pole single-value capacitor motor designed for three-speed unit-heater fan service to be used with an autotransformer for speed control.

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A New Current-Limiting Fuse

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A. P. STROM, MEMBER AIEE
H. W. GRAYBILL, ASSOCIATE AIEE

Synopsis: Increasing concentration of power combined with the desire for more compact switchgear assemblies has created a demand for small, totally enclosed, high-interrupting-capacity fuses suitable for potential and operating transformer protection. The current-limiting fuse meets these requirements for it is inherently a high-interrupting-capacity fuse of low current rating and can be totally enclosed in a small space.

The theory and construction of previous current-limiting fuses are briefly described. The theory and construction of a new current-limiting fuse is given. The new fuse is simple in theory and construction. Its fundamental elements can be separated, studied, and tested, making it possible to predict an unusual degree of reliability and freedom from voltage surges. Test results confirm the reliability, high interrupting capacity, and freedom from voltage surges of the new fuse.

THE development and adoption of the first current-limiting fuses were prompted by the need for high interrupting ability. The other characteristics of the fuse were merely incidental and were not major factors in the wide acceptance of the current-limiting fuse in Europe. To limit the current and thereby limit the amount of energy liberated in the fuse was one way of obtaining high interrupting ability. In fact, before the advent of boric acid, as an interrupting medium, the current-limiting fuse was the only fuse that could safely be applied to many of the systems then in existence. During 1931 current-limiting fuses were imported, tested, and studied for possible adoption in this country where high interrupting ability was required. These fuses had the desirable features of high interrupting ability in a relatively small size and did not expel arc gases or other material during operation. However, the limited range of current ratings available in the fuse so restricted the scope of its application that its commercial development for use in this country was abandoned. Further development evolved the boric acid fuse with its high interrupting ability, totally enclosed features, and wide range of current ratings.

The increased use of metal-enclosed switchgear has placed a premium on space. The amount of room required for a low-interrupting-ability fuse with current-limiting resistor or a standard power fuse for the protection of potential or small operating transformers appears to be all out of proportion to the size of the apparatus being protected and the load handled. It should be remembered, however, that the real duty of the fuse is to protect the system rather than the apparatus. There is a need, therefore, for a fuse having the small size and characteristics of the current-limiting fuse for connecting small loads to high-power systems as a supplement to power fuses that are used for heavier capacity loads.

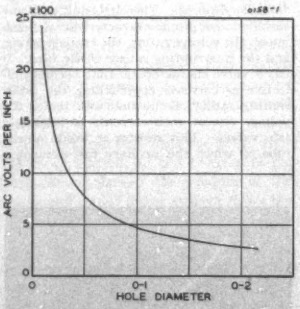

Figure 1. Characteristics of arcs in small holes

At the present time there are two types of current-limiting fuses available. One type consists of a fuse and resistor in series enclosed in a common cartridge. The resistor limits the current during the interruption of the fuse. The required characteristics of a resistor to carry load current and to limit the current on short circuit are directly opposed. To satisfactorily combine both characteristics in one resistor requires a relatively large resistor that necessitates a bulky cartridge.

The other type of current-limiting fuse consists of a silver wire spirally wound on a ceramic core and surrounded by inert crystals.[1-4] This type of fuse has had an excellent record in Europe for over a decade and in this country for two years. Characteristics of this fuse believed capable of improvement are:

1. It has a high melting temperature and, therefore, if made in higher ampere ratings would have a high operating temperature.
2. It offers no flexibility in obtaining time-current characteristics to meet various applications.
3. On operations at currents slightly above the melting point of the wire the operation may not be as reliable as in a spring-operated fuse.
4. The reliability of the fuse depends on the characteristics of the inert crystals used, therefore, a reliable source of supply and very rigid inspection are necessary to maintain the quality of the fuse.

Early tests on various forms of current-limiting fuses revealed high voltage surges during current limitation. Small variations in construction would result in widely different surge voltages. In order for a fuse to limit the current a voltage must be produced in the fuse equal to or greater than the voltage available in the circuit at the time of current limitation. Also the voltage produced must not rise to a value that might cause flashover or otherwise endanger the circuit on which it is applied. It is evident, therefore, that in order for a current-limiting fuse to be

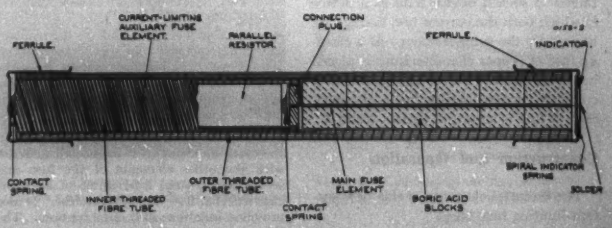

Figure 2. Sectional view of new-type current-limiting fuse

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1. For all numbered references, see list at end of paper.

reliable the voltage rise during current limitation must be accurately controlled and kept within a definite range. A further requirement of reliability is that the means for controlling the voltage rise should not be critical or susceptible to the small variations in size or material that are liable to occur in commercial production.

Investigations on arcing characteristics revealed that arcs drawn in small holes in

Figure 3. Photograph of new current-limiting fuse

solid material gave a high arc voltage that increased very rapidly as the size of the hole was reduced.[3] This characteristic is shown by the curve in figure 1. By utilizing a very small hole, a very high arc voltage and therefore a very definite current-limiting action can be obtained. The smaller the hole, the higher the arc voltage and the more reliable the current-limiting action will be, disregarding any possible danger to the system from the high voltage.

To limit the voltage on any device it is merely necessary to by-pass the current through a suitable resistor. This resistor may have a valve characteristic to limit the current at normal voltage and permit much higher currents to flow at higher voltages. If the fuse wire in a very small bore is paralleled with such a resistor, the basis is formed for a current-limiting fuse with a very definite and reliable current-limiting element and a very definite and reliable voltage-limiting element. A greater degree of reliability can be attained in such a device than in a device in which both the current and voltage are limited by the same element. If a clean-up fuse of proper characteristics is placed in series with such a combination, a complete current-limiting fuse is obtained. Such a fuse is shown in figures 2 and 3.

Construction and Operation

The essential elements of this new current-limiting fuse are:

1. *The Auxiliary or Current-Limiting Fuse Element.* This consists of a silver wire spirally wound on a multipitch threaded fiber tube which is screwed into a similarly threaded tube that forms the outer shell of the fuse holder. Fiber was selected for this purpose due to its gas-evolving properties and its mechanical strength although numerous tests have not demonstrated the need for any great mechanical strength in these parts. With gas-evolving material around the fuse element the arc voltage will be higher than with nongas-evolving materials. Furthermore, residual arc currents will be interrupted quickly with no possibility of a low-resistance path due to incandescent surfaces. The clearance left in the bottom of the thread after assembly provides a small hole slightly larger than the diameter of the wire, in which arc restriction occurs. On assembly a special cement is applied to the threads to form a seal between threads. Even with loose fitting parts the arc voltage produced in the restricted hole is many times the voltage required for current transfer to the parallel resistor rod.

2. *The Parallel Resistor Rod or Voltage-Limiting Element.* This element is a silicon-carbide rod of proper characteristics depending on the voltage rating, the current rating, and the interrupting rating of the fuse. It has a valve characteristic that becomes effective at currents approaching the interrupting rating of the fuse and limits the voltage rise at such currents to relatively safe values. This resistor is inside of the tube on which the auxiliary fuse element is

Figure 4. Dynamic volt-ampere characteristic of auxiliary fuse on 500-ampere 10x100-microsecond current wave

wound. Connection is made to it by means of contact springs. No special precautions are necessary in making contact with the resistor, as it passes current only during arc interruption, when full line voltage is impressed across the fuse.

3. *The Main Fuse Element.* This element, the clean-up element, is connected in series with the other elements of the fuse and serves as the final interrupter of all overcurrents that flow through the fuse. It also provides isolation after interruption. The fuse element operates in a small hole through solid boric acid. The excellent performance of boric acid in fuses both on low and high currents has been described in previous publications and has been demonstrated by many years in commercial use.[2] In the new current-limiting fuse this interrupting element is subjected to very easy service since it is called upon to open either extremely low currents or moderately low currents at a high power factor. The main fuse element itself is of the low-temperature type, can be designed to give any

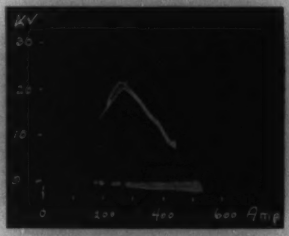


Figure 5. Dynamic volt-ampere characteristic of auxiliary fuse with parallel resistor rod on 500-ampere 10x100-microsecond current wave

desired time-current characteristics, and is spring operated to insure a positive gap on low-current operations. The spring that separates the fuse element also operates a suitable indicator that provides visual indication of a blown fuse.

The action of the fuse on low currents is not the same as on high currents due to the main fuse element being calibrated to melt at a lower current than the auxiliary fuse element. This was done to prevent any appreciable temperature rise of the auxiliary silver fuse wire and eliminate the possibility of the auxiliary fuse being melted before the main fuse. On low values of current the main fuse element may melt and interrupt the current without the auxiliary fuse wire being melted. In a fuse designed for potential-transformer protection this will happen on all currents below approximately 80 amperes. On high-current operation, the auxiliary fuse will melt on the initial rise in current and transfer the current to the parallel resistor rod. The thermal capacity of this rod is sufficient to permit a half cycle of current to pass through it without an excessive temperature rise. At the end of the first half cycle after current transfer the main fuse will interrupt the circuit.

Theory and Calculations

The operating characteristics of the current and voltage-limiting elements of

this fuse are of particular importance. Calculations can readily be made from which the performance of the device may be predicted.

When a short circuit occurs the current rises in the auxiliary fuse element with practically no limiting influence until the fuse element melts. At this point voltage rises rapidly to a high arc voltage and the current is limited and transferred to the resistor rod.

The maximum value which the current

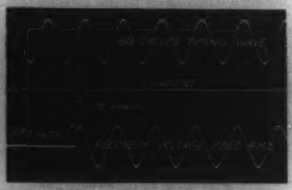


Figure 6. Operation of current-limiting fuse on a 2.3-kv system, with 20,000-ampere available short-circuit capacity

may reach when the fuse melts may be readily computed. Since the temperature rise of the fuse wire equals

$$\frac{\text{energy input}}{\text{mass} \times \text{specific heat}}$$

an infinitesimal temperature rise,

$$dT = \frac{i^2 R(1+aT)dt}{Mk} \qquad (1)$$

where

T = temperature, degrees centigrade
i = amperes
t = seconds
R = fuse resistance at zero degrees
a = temperature coefficient of resistance
M = mass of fuse wire, grams
k = watt seconds per gram per degree centigrade

The maximum rate of current rise occurs on symmetrical short circuits. Under such conditions we may, for simplicity and without appreciable error, assume that the current in the fuse wire up to the melting point is linear and equal to:

$$i = 377 I_m t \qquad (2)$$

where I_m = maximum value of available 60-cycle short-circuit current.

We may then rewrite equation 1 as follows:

$$\frac{dT}{R(1+aT)} = \frac{(377)^2 I_m^2}{Mk} t^2 dt \qquad (3)$$

Integrating equation 3, taking T between the limits of the initial fuse temperature, T_i, and the melting temperature, T_m, gives:

$$\frac{1}{Ra} \log_e \frac{1+aT_m}{1+aT_i} = \frac{(377)^2 I_m^2}{Mk} \frac{t_m^3}{3} \qquad (4)$$

whence time to the melting point,

$$t_m = \sqrt[3]{377 I_m \cdot \frac{3Mk}{Ra} \log_e \frac{1+aT_m}{1+aT_i}} \qquad (5)$$

Substituting this value of t in equation 2, gives the current at time of melting.

$$i_m = \sqrt[3]{377 I_m \cdot \frac{3Mk}{Ra} \log_e \frac{1+aT_m}{1+aT_i}} \qquad (6)$$

Whence

$$i_m = K \sqrt[3]{I_m}$$

This indicates that as the available system short-circuit current rises, the maximum value of the initial rush of short-circuit current in the fuse increases only as the cube root of the available short-circuit current. Thus, if the available short circuit increases from 10,000 to 80,000 amperes, the maximum value to which current can rise in the fuse will only double.

This is important since the initial voltage surge caused by the blowing of the fuse cannot exceed the product of the maximum initial fusing current times the resistance of the parallel resistor rod. It is, therefore, possible to design this fuse so as not to exceed any specified surge voltage. Since ordinary switching operations frequently cause voltage surges of twice the peak system voltage it is evident that the fuse may safely be designed to have twice peak value as an upper limit of surge voltage when the parallel fuse melts. Thus, if the fuse is designed to give a maximum surge voltage on a 10,000-ampere system, equal to peak voltage, then, since the surge varies as the cube root of the available system current, a short circuit on an 80,000-ampere system can be interrupted without exceeding a surge of twice the peak voltage. This indicates that a fuse of this type can cover a wide range of short-circuit currents without subjecting connected apparatus to excessive voltage surges.

As previously mentioned, it is further possible to make use of valve characteristics of the material in the parallel resistor rod, thus still further extending the range to which the fuse may be applied without excessive voltage surges.

Test Results

Important features of this fuse are the current-limiting fuse element and the voltage-limiting parallel resistor. The high arc voltage produced in the current-limiting fuse element and the effect of the parallel resistor in limiting that voltage are well illustrated in the oscillograms shown in figures 4 and 5. The tests represented by these oscillograms were made on a surge generator. Figure 4 shows the dynamic volt-ampere characteristics of the auxiliary fuse alone, while figure 5 shows the same characteristic of the auxiliary fuse and parallel resistor.

Numerous tests were made during the development of this fuse. Figures 6 and 7 show typical oscillograms of short-circuit interruptions on the fuse as finally perfected.

In figure 6 an interruption is shown on a 20,000-ampere 2,300-volt circuit. The fuse used in this test was similar to the illustration shown in figure 3, but of much smaller size, having an over-all length of only $4^1/_8$ inches. In this test it may be noted that the initial rush of current was limited at 175 amperes, while the surge voltage barely exceeded the peak value of the restored voltage.

Figure 7 shows an interruption on a 20,000-ampere 13.2-kv circuit. The fuse used in this test was as shown in figures

Figure 7. Operation of current-limiting fuse on a 13.2-kv system with 20,000-ampere available short-circuit capacity

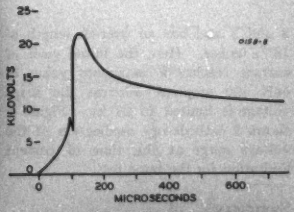


Figure 8. Cathode-ray oscillogram of voltage surge occuring on interruption shown in figure 7

An Electrical Governor

FRANK I. MORGAN
MEMBER AIEE

THE advantages obtained from the application of electrical methods of control to all classes of machinery, suggested to inventors the idea of regulating the speed of prime movers by electrical means. Frequent attempts have been made to accomplish this result. Many of these governors were very ingenious, but for one reason or another they never came into general use.

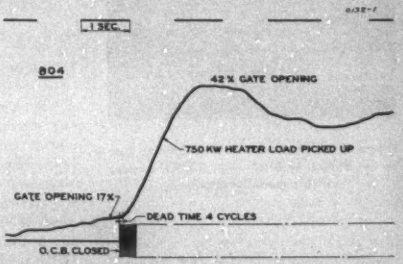
The electrical governor described in this paper is the result of several years effort to develop a practical method of electrically controlling and regulating the speed of hydraulic turbines.

Briefly, the method utilizes a form of frequency meter which measures variations in the frequency (corresponding to changes in speed) of an alternating current supplied by the generator driven by the turbine to be governed. This meter, through suitable control equipment, moves a pilot valve, which in turn controls the operating engine that opens or closes the wicket gates of the turbine.

An application of the scheme has been made to a 3,000-horsepower turbine operating under a head of 55 feet. The present installation is entirely experimental, the equipment being "home-made" and crude but the results obtained have been quite encouraging and indicate that the method has interesting possibilities.

A very steady speed is maintained at no load and synchronizing is done without difficulty with the governor in control of the unit. Operation under load is quite satisfactory, the governor responding promptly to small fractions of a cycle change in frequency (60 cycle). Changes in the loading of the machine are easily made, the governor responding instantly to such adjustments. Loads requiring gate openings of 80 to 90 per cent have been suddenly dropped by opening the generator circuit breaker. The governor closed the gates promptly and there was no tendency to "hunt" about the no-load position. Sudden accessions of load such as large "across the line" motors, are followed instantly by the opening of the turbine gates with no hunting whatever. The unit has been started from standstill many times by electrical remote control and when approximate normal speed was reached, placed under governor control by throwing a switch.

Figure 1. 750-kw load applied



Some of the advantages of electrical governing are:

(*a*). Small inertia of the control element.

(*b*). Increased sensitivity.

(*c*). Elimination of long rods, cables, bell cranks, etc., required for the compensation devices of fly-ball governors.

(*d*). Since, with electrical control, the force operating the pilot valve can be made large, and is independent of the amount of the speed change, friction in this valve has little or no effect.

(*e*). The possibility of mounting the control element at any convenient location, such as on the main switchboard.

(*f*). The valve controlling the admission of pressure fluid to the servomotor can be mounted immediately on this cylinder thus reducing the amount of piping and releasing valuable floor space ordinarily required for governors.

(*g*). Ease of starting and stopping the turbine by remote control. This permits *complete* control of the unit by the switchboard operator.

(*h*). Ease of applying frequency and load control methods.

(*i*). By means of simple test equipment, the sensitivity of the control element (frequency meter) of an electrical governor can be checked. A corresponding check of a fly-ball device is more difficult and complicated.

The writer is of the opinion that a description of the device and an account of the progress made up to the present, may prove of interest to engineers in general, and more particularly to those who are intimately concerned with governing problems.

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FRANK I. MORGAN is maintenance engineer, Pennsylvania Water and Power Company, Baltimore, Md.

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2 and 3 and has an over-all length of $12^1/_2$ inches. Here the initial rush of current reaches a maximum value of only 400 amperes, whereas the surge voltage is limited to 23 kv. Figure 8 shows a cathode-ray oscillogram of the voltage surge at the time of current limitation for the same test.

Summary

1. A new type of current-limiting fuse has been developed and tested.

2. The construction of the fuse is such that the voltage surge as well as the current surge during interruption is limited to definite and predetermined values.

3. Tests on high-capacity systems have not revealed the limitations of the fuse. Indications are that the fuse has an exceedingly high interrupting ability.

4. The design of the fuse is flexible. Time-current characteristics can be obtained as desired.

5. The fuses may be applied to the protection of potential transformers and other apparatus of small power consumption. They are especially applicable to use in enclosed switchgear.

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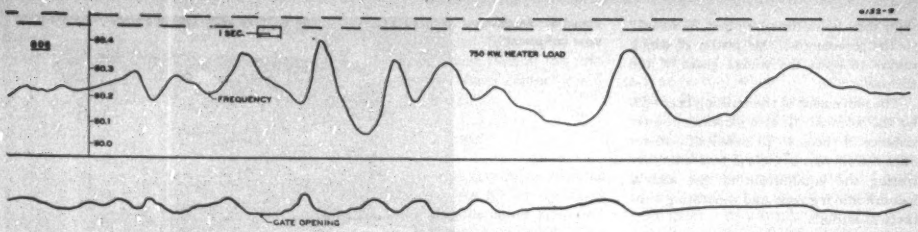


Figure 2. Frequency-gate movement

Preliminary Tests

The three tracings of oscillograms shown are a record of the performance of the governor during preliminary tests made in January and May 1937. These records are submitted, not as an indication of what can ultimately be accomplished, but simply to show the progress made up to the time of these tests.

The load on the unit during these tests was a purely resistance one amounting to 750 kw and it was possible to throw it on and off the unit at will.

Figure 1 (oscillogram number 804) shows the operation of the governor when a load of 750 kw was suddenly thrown on the unit. The governor started to open the gates in the remarkably short time of 4 cycles (60-cycle basis).

Figure 2 (oscillogram number 806) shows frequency and gate opening variations while the unit was carrying the load mentioned above.

Figure 3 (oscillogram number 808) gives the result of dropping load tests, showing the action of the governor when the load of 750 kw was dropped by opening the generator circuit breaker. The time required for the governor to start closing the gates varied from six to nine cycles.

Subsequent to the tests described in the foregoing, the apparatus has been applied to a double runner 13,500-horsepower turbine. This unit is equipped with a standard fly-ball governor of an old design. The control of its pilot valve was transferred from the flyballs to the electrical governor. The speed regulation, after the change, was very satisfactory and far superior to that obtained with the flyballs in control.

Operating Principle

An instrument sensitive to frequency variations and having two parallel electrical circuits, one branch containing resistance and the other reactance, is used as the control element. The change in impedance of the reactance with frequency is balanced by a corresponding change in resistance so that the currents flowing in the two branches of the circuit are maintained equal in value. The required changes in resistance are obtained by means of variable rheostats. Being a "null" method, the action of the control element is unaffected by changes in voltage within wide limits.

Referring to the schematic diagram, figure 4, *A* is a Kelvin balance employed as the frequency-responsive element, the moving coils of which are provided with a contact 27. This contact engages with either of the stationary contacts, 28 or 29. A resistance 10, is connected to one set of coils 3, and a reactance 11, to the other set of coils 2, of the Kelvin balance. Solenoids 24 and 25 actuate the walking beam 22, to which is connected the valve 18, admitting pressure fluid to either end of the "servomotor" cylinder 1. Rheostats 12 and 13 provide "compensation", the movable contact of rheostat 12 being connected to the servomotor piston rod by lever 30. The movable contact of rheostat 13 is connected to lever 30 by rod 33 and springs 31. A dashpot is provided to delay the movement of the contact of rheostat 13.

"Inherent speed drop" (also called "degree of irregularity," or the decrease in speed between no load and full load necessary for parallel operation) is adjusted by changing the location of the pivot point of rod 33 on the lever of rheostat 13.

The speed maintained by the governor is adjusted by means of rheostats 14.

Operation

Assuming normal frequency and steady load conditions, the currents flowing through the two sets of coils of the Kelvin balance are equal and the moving coils are in equilibrium, contact 27 being midway between contacts 28 and 29. Now, if the load on the unit increases, the speed will drop, lowering the frequency. Because of the lowered frequency, the reactance of 11 is decreased permitting more current to flow through coils 2 of the balance, upsetting the equilibrium of the moving coils. Contacts 27 and 29 close, energizing solenoid 24 which moves walking beam 22 and valve 18. Pressure

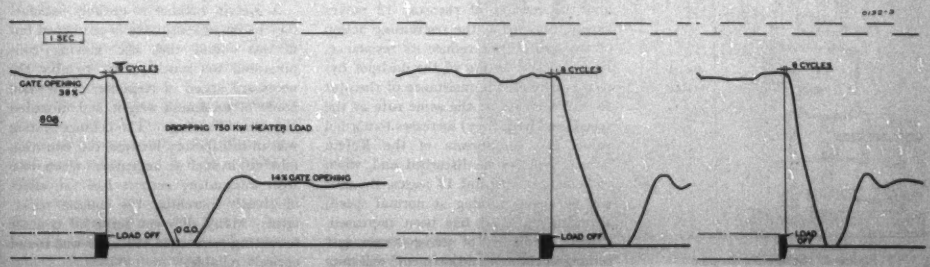


Figure 3. Dropping load tests

fluid then flows through pipes 20 and 21 to the servomotor, the piston of which moves to open the wicket gates of the turbine.

The movement of the walking beam 22, by the solenoid 24, also increases the resistance of rheostat 15 sufficiently to reduce the current in coils 2, to normal, restoring the equilibrium of the Kelvin balance moving coils and separating contacts 27 and 29.

The opening of the wicket gates by the servomotor increases the resistance of rheostat 12 by moving lever 30. This additional increase of resistance in series with coils 2 unbalances the moving coils in the opposite direction, closing contacts 27 and 28 to energize solenoid 25, which moves walking beam 22. This results in return of valve 18 toward its neutral position, and at the same time, decreases the resistance of rheostat 15. It should be noted that the movement of valve 18 back to its neutral position is simultaneous with the opening of the gates by the servomotor and the increase in resistance of rheostat 12.

When the resistance of rheostat 12 has been increased by an amount equivalent to the decrease in impedance of reactance 11 and the increase in resistance of rheostat 15 by the initial movement of the walking beam, the equilibrium of the Kelvin balance is again restored and valve 18 has been brought back to its neutral position, stopping movement of the gates.

The wicket gates have now been opened to increase the amount of water to the turbine, but because of the inertia of the water, its flow does not immediately increase. During the time the gates are being opened to the new load position and until the flow of the water increases sufficiently, the additional load demand is met by energy stored in the revolving parts of the turbine and generator which is released by a decrease in speed. As the flow of water increases through the greater gate opening, the speed of the unit returns toward normal. Unless provision is made to prevent it, this increase in speed (and frequency) toward normal would upset the equilibrium of the Kelvin balance—which has been balanced for the lowered speed of the unit by the change in resistance of rheostat 12—and cause a closing movement of the gates. This is avoided through the action of springs 31, rheostat 13, and the dashpot. (Second compensation.)

The tension of the spring 31 has been increased by the movement of lever 30, and the contact of rheostat 13 moves slowly, because of the restraining action of the dashpot, to reduce its resistance. Provided the setting of the dashpot bypass is correct, the resistance of rheostat 13 will decrease at the same rate as the speed (and frequency) increases to normal value, the equilibrium of the Kelvin balance will not be disturbed and, when movement of rheostat 13 ceases, the unit will be again running at normal speed, although the load has been increased. Circuit conditions of the governor (assuming isochronous adjustment) will then be exactly as they were before the change of load occurred.

It is apparent that increasing the resistance of rheostat 14, has the same effect as an increase in impedance, of reactor 11, resulting from an increase in speed (and frequency) of the turbine. Such an increase of resistance will cause the governor to close the turbine gates by a definite amount and lower the turbine speed.

Conversely, a decrease in resistance of rheostat 14 will cause the governor to open the turbine gates and increase the speed of the turbine.

The action of the governor on a decrease in load is, practically, the reverse of that described in the foregoing.

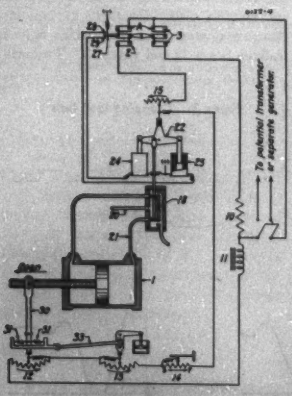
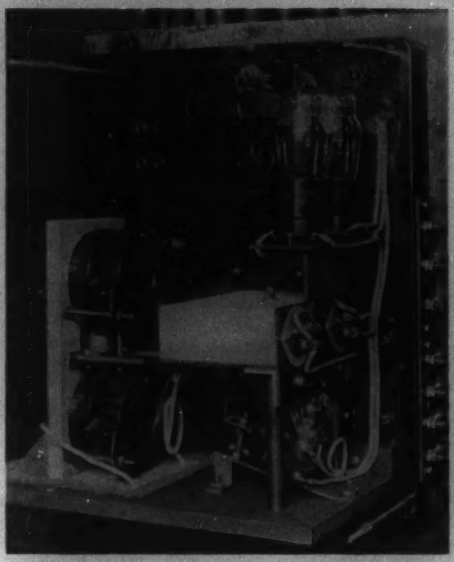


Figure 4. Schematic diagram

Figure 5. Magnetic vane instrument



Control Instrument

A Kelvin balance is entirely satisfactory as far as sensitivity is concerned but it was found that the moving coils possessed too much inertia to give the necessary speed of response, even when made of minimum weight and mounted in jeweled bearings. The contact system was unsatisfactory because the vibration inherent in such an instrument when used with alternating current had the effect of greatly increasing the contact resistance. Many different forms of contact mounting were tried but none was found entirely reliable.

A magnetic vane instrument, shown in figure 5, was constructed and substituted for the Kelvin balance. The moving element of this instrument consists of a small aluminum shaft fitted with steel pivots, on which two light annealed steel vanes are mounted. This shaft is supported in jeweled bearings. Each vane is surrounded by a coil, one of which is connected in series with resistance 10, the other being connected in series with reactance 11. The vanes are placed on the shaft at an angle of approximately 80 degrees with respect to one another so that, with current flowing through the two coils, they tend to move in opposite directions and the shaft assumes a position depending on the relative strengths of the currents in the two coils. The moving element is dampened by a small oil dashpot. A small mirror is mounted on the shaft midway between the ends.

Light from a 21 candle-power automobile head lamp is reflected from the mirror to two photoelectric cells which are connected to the grids of two vacuum tubes. The two coils of a differential relay of the D'Arsonval type are connected in the plate circuits of the tubes. The contacts of this relay control the solenoids 24 and 25 which operate valve 18.

The use of a lamp and vacuum tubes naturally raises the question of reliability since that feature is of paramount importance in a governor.

Records of lamp life, in continuous telemeter service, have shown that the life of such lamps (6–8 volts) when operated at 4 volts, varied from 12,000 to 19,000 hours.

An effective means of insuring reliability is the use of a double filament lamp (number 2331) and two sets of vacuum tubes. A simple one-contact relay operates to connect the second set of tubes and the second lamp filament in the event any one filament fails in the first set. If desired an alarm contact could be added to the relay.

Power Requirements

The magnetic vane instrument requires about 30 volt-amperes for its operation including the 21 candle-power lamp and the filaments of the vacuum tubes. This indicates that the load on a potential transformer for this type of governor would be quite negligible and makes feasible the use of a small magneto for this purpose if it were considered undesirable, from the standpoint of reliability, to use potential transformers.

Figure 6. Compensation rheostats

Governor Action on Loss of Load

When a heavy load is suddenly dropped from a hydraulic turbine, the speed immediately increases and the governor promptly closes the gates. Because that part of the compensation device (second compensation) which contains the time delay feature acts slowly, the speed reaches its highest value and decreases toward normal before the time delay element has returned to the point where it can function properly for the gate opening required to maintain normal no-load speed. As a result, when the speed decreases sufficiently to cause the flyballs to start opening the gates, the second compensation cannot operate properly and the gates are opened far beyond the point necessary to maintain normal speed at no load. The turbine overspeeds, causing the flyballs to again close the gates completely. During each interval of gate closure, the second compensation approaches the position where it can function properly. Until it reaches this point, these gate opening and closing cycles repeat at intervals with gradually decreasing amplitude. The effect, for the time being, is much the same as that which would be obtained if the second compensation feature were omitted.

This objectionable operation has been remedied in one well-known make of governor by means of a cam which increases the action of the spring which opposes the centrifugal force of the flyballs. This cam begins to be effective when the gates, on closing, reach the point which admits sufficient water to operate the turbine at about normal speed with no load. The cam increases the "regulation" of the governor at no load, i.e., it adjusts the flyballs so that the speed maintained at no load is considerably higher than that at full load. In other words, the cam provides additional compensation for a limited range of gate movement. In this way, as the turbine

Figure 7. Pilot-valve solenoids

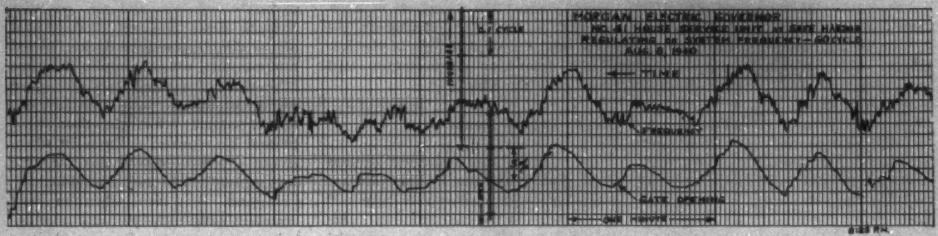


Figure 8. Record of test made August 8, 1940

slows down, the flyballs start to open the gates sooner than they would had no adjustment been made, the downward trend of the speed is arrested earlier and the second compensation functions properly. In addition, the opening movement of the gate is stopped at a point at which the readjusted speed will be maintained.

In at least two other makes of governors, this surging of gate movement and speed after dropping heavy loads is avoided by the provision of a bypass for the dashpot, which is opened automatically when quick gate movements beyond a certain amount occur.

In the governor described above, a bar is used to connect the movable levers of the compensation rheostats 12 and 13. This bar is slotted at the end connected to the lever of rheostat 13, as can be seen in figure 6. The purpose of this bar is the return of the lever of rheostat 13, on large, quick gate movements to a point where the second compensation can function properly. The slot allows the second compensation to operate normally on small gate movements or large gate movements which do not take place rapidly. This method of overcoming the faulty operation mentioned above has the advantage that no change is made in the regulation of the governor.

Load Limit and Safety Devices

Limitation of the load carried by the unit can be accomplished by arranging a stop, operated by an electromagnet, to prevent movement of walking beam 22 and valve 18 to cause further opening of the gates. The electromagnet would be energized through suitably arranged contacts to be closed by lever 30, these contacts to be adjustable so that the gate opening could be limited to any degree desired. This arrangement would not interfere with the closing of the gates at any time.

Emergency shutdown of the unit could be accomplished by the use of a relay, which when de-energized, would release a spring to move the pilot valve, independently of solenoids 24 and 25, in the direction to close the turbine gates. The relay releasing the spring could be operated by over-speed, over or undervoltage, decrease in governor fluid pressure below a definite value, etc.

Conclusion

No claim is made that the method of governing described in the foregoing is the ultimate solution of the problem of regulating the speed of hydraulic turbines. It is readily apparent that the results obtained, so far, with this experimental setup, are more or less academic in value, and that the real worth of the method can only be determined by considerable operating experience which will bring out the weak points and emphasize those which are of advantage.

One possibility which may be deserving of consideration is the ease with which this equipment can be applied to obsolete or antiquated pressure operated governors and thereby secure the sensitivity and satisfactory operation of a modern governor without the expense of replacing the entire installation.

A High-Power Oilless Circuit Interrupter Using Water

W. M. LEEDS
MEMBER AIEE

THE oil circuit breaker has been for many years the standard type of circuit interrupter for heavy-duty powerhouse service. Since the introduction of modern arc-rupturing devices into these circuit breakers, the occurrence of serious trouble attributable directly to oil switchgear failure has been rare. However, the appearance on the market of various types of oilless circuit breakers of considerable interrupting capacity has encouraged the idea that the complete elimination of oil in power house switchgear may be both desirable and practicable. Further experimental investigation and development activity on the part of switchgear manufacturers seems to indicate that currents of 60,000 amperes or more at 13,200 volts can be interrupted satisfactorily in circuit breakers using either air or water as the arc-quenching medium. This paper describes the construction and operating characteristics of a high-power water circuit breaker.

Water Circuit Breakers

Interrupters using water as the extinguishing medium have a history of some 15 years, and are now used fairly extensively in moderate interrupting capacities, particularly in Germany.[1] In the form designated as "expansion breaker", the arc is drawn in a confined chamber where the generation of steam and gas quickly builds up a high pressure. The chamber is usually constructed of one or more sections resiliently mounted so that passages to a condensing chamber are opened up by the pressure, as indicated in figure 1. It is claimed that the deionization of the arc space is greatly accelerated by the cooling effect accompanying the sudden expansion of the steam. In any case, it is certain that the arc is subjected to a turbulent blast of steam and gas as these arc products make their escape laterally or longitudinally from the recesses in the interrupting chamber. The combined effect of cooling and turbulence causes dielectric strength to be built up with sufficient rapidity that the arc will not restrike.

Since even distilled water is a relatively poor dielectric the moving contact must be lifted clear of the water, and in many designs moved completely out of the chamber so as to interpose a series air break. The condensation of a large proportion of the vapors considerably reduces the external demonstration as compared with an oil breaker, the operation being somewhat quieter than an air switch. Factors which prevent this device from fulfilling the requirements of an ideal breaker include contamination and loss of water, and the possibility of corrosion of metal parts and deterioration of the insulation exposed to water or steam. Nevertheless, these problems are not at all insuperable, and high-capacity water breakers of the type described have been made experimentally for ratings up to 1,500,000 kva at 15 kv.

Water-Breaker Construction

Investigations on the breakdown of water under electric stress, by J. Slepian, C. L. Denault, and A. P. Strom,[2] indicate the desirability of not only removing voltage completely from the interrupting chamber immediately after opening the circuit, but also closing the circuit by an air switch rather than in the water. The experimental water-breaker pole unit shown in figure 2 is arranged with a series disconnect switch and also a main paralleling switch for continuous-current-carrying ratings of 1,200 amperes and above. The pole-unit mechanism is arranged to give the following sequence of operation:

Closing

1. Arcing contacts close in water.
2. Series disconnect switch completes the circuit in air.
3. Main switch closes, paralleling the arcing contacts and disconnect switch.

Opening

1. Main switch opens, diverting the current through the arcing contacts.
2. Arcing contacts open, extinguishing the arc in the water chamber.
3. Series disconnect switch opens, removing potential from the interrupter.

The different positions of the breaker contacts are illustrated in figure 3.

Although condensation reduces the amount of gas vented to the outside of the breaker, heavy local pressure impulses created in the neighborhood of the arc, when interrupting very high currents require exceptionally strong construction of the main body of the interrupter. Figure 4 is a cross section of the interrupting chamber. Overlapping inside and outside bronze cylinders *A* hold a heavy insulating tube *B* in compression and shear to develop maximum strength. Special attention has been given to the problem of shock absorption by providing a large air volume above the water level and also by utilizing the compressibility of air pockets sealed in rubber *C* located in the removable bottom bronze bell cover *D*.

The stationary arcing contact assembly consists of a cluster of fingers *E* while the arcing contact itself is made of a strong rustproof alloy rod *F* with a tip of arc-resisting material. This contact moves in and out of a chamber formed by three large blocks *G* of special insulating material with a centrally located water trapping pocket in each. A hollow spacer *H* above these blocks engages a rubber ring *I*. Pressure under the lowest block raises the whole arcing chamber assembly, compressing this rubber ring and at the same time opening the vent *J*.

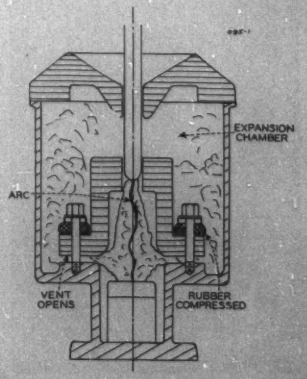


Figure 1. Siemens expansion breaker for low voltage

Paper 40-85, recommended by the AIEE committee on protective devices, and presented at the AIEE summer convention, Swampscott, Mass., June 24-28, 1940. Manuscript submitted November 13, 1939; made available for preprinting April 23, 1940.

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Among those of the author's associates who have aided in the development of this water breaker he wishes to acknowledge particularly the contributions of A. J. A. Peterson and A. H. Bakken in creating a workable mechanical design and the untiring efforts of B. P. Baker in following through the construction and testing of the experimental pole unit.

1. For all numbered references, see list at end of paper.

Table I. Interrupting Test on Experimental Water Breaker

13,200 Volts, Single Phase, 60 Cycles

Test	Current (RMS Amperes)	Interrupting Time (Cycles)	Arc Duration (Cycles)
Series A			
1	28,000	4.7	1.7
2	47,500	4.6	1.5
3	34,500	4.8	1.8
4	61,000	4.5	1.5
Series B			
1	9,100	4.3	1.4
2	7,500	4.3	1.5
3	25,000	4.4	1.6
4	27,500	4.4	1.6
5	37,500	4.3	1.6
6	26,000	4.2	1.4
7	51,000	3.9	1.2
8	29,000	4.2	1.4
9	44,000	4.3	1.4
10	35,000	4.6	1.7
11	58,000	4.2	1.3
Series C			
1	1,420	5.1	2.1
2	4,750	4.7	1.7
3	4,500	4.3	1.4
4	5,100	4.4	1.6
5	4,900	4.2	1.3
6	34,000	4.2	1.2
7	30,700	4.3	1.3
8	37,000	4.3	1.3
Series D			
1	50	4.2	1.3
2	50	3.8	0.9
3	150	3.2	0.3
4	150	3.5	0.6
5	290	4.5	1.6
6	295	4.5	1.6
7	620	4.4	1.5
8	600	4.8	1.6
9	910	4.2	1.3
10	810	3.7	0.8

Figure 2. 15-kv water breaker experimental pole unit set up for interrupting tests

While research work by Kesselring and others in Germany might seem to have shown that arcs can be extinguished by the cooling action accompanying sudden expansion of saturated vapors surrounding an arc, it is not believed that this high-power water breaker operates in quite the same manner. For instance, no attempt is made to synchronize the opening of the vent and resultant vapor expansion with the instant of current zero. When interrupting a high-current arc, the vent *J* begins to open during the first half cycle of arcing. As the contact tip draws the arc *K* into each successive water pocket, more steam and dissociated gases are formed which turbulently mix into the arc stream

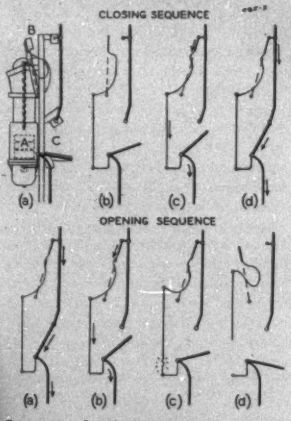

Figure 3. Switching sequence of water-breaker pole unit

A—Arcing break in water chamber
B—Series air disconnect
C—Main paralleling switch

Closing sequence:
(*a*) Open, (*b*) arcing contacts closed, (*c*) disconnect switch closed, (*d*) main contacts closed

Opening sequence:
(*a*) Closed, (*b*) main contacts opening, (*c*) arcing contacts opening, (*d*) disconnect switch open

on their way to the vent *J*. It should be noted further that the upward displacement of the interrupting elements *G* and *H* as the rubber ring *I* is compressed reduces the volume of the space between the upper block and the contact guide. This results in a quantity of water being forced in a longitudinal flow down along the contact and into the arc stream, tending to sweep the arc products downward and away from the contact tip. The de-

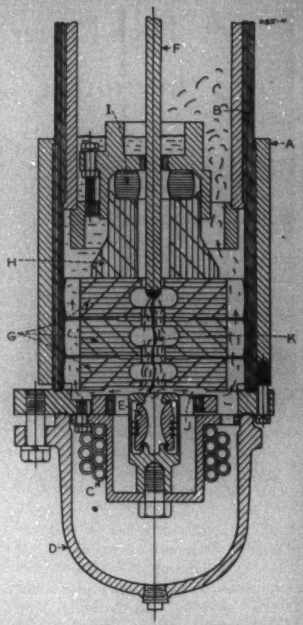

Figure 4. Cross section of interrupting chamber

A—Micarta tube
B—Bronze cylinders
C—Air-filled rubber
D—Bottom bell cover
E—Finger contacts
F—Arcing contact rod
G—Micarta blocks
H—Hollow spacer
I—Rubber ring
J—Arcing chamber vent

ionization produced by the turbulent flow of the relatively cool water vapor and steam through the arc space is so effective that at the first or second current zero after the arc is drawn into the bottom of the arcing chamber, the dielectric strength builds up with sufficient rapidity that re-ignition cannot take place and the arc is extinguished.

When interrupting lower currents the valve-type vent *J* opens only a very small amount, maintaining fairly high pressure in the arcing chamber. This keeps the gas bubble small, so that effective deionization is still obtained and the arcing time is only slightly longer than at high currents. By using only the one vent at the bottom instead of at several points along the arc stream all of the gas is

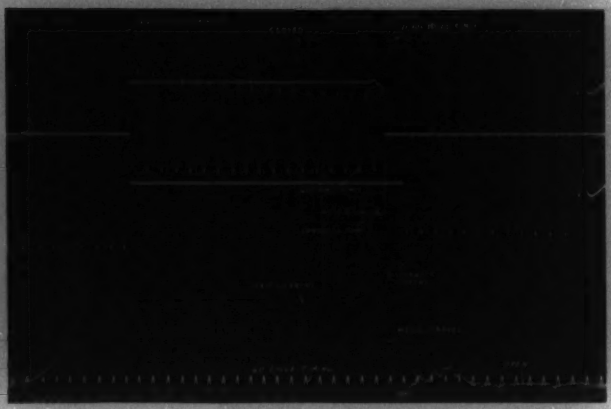

Figure 6. Oscillogram of low-current interruption at 13,200 volts

forced through the restricted arc passage and the deionizing action thus intensified.

The steam and gas from the vents are directed through a condensing labyrinth, shown in figure 5, and the permanent gases such as hydrogen and carbon monoxide that remain after the water vapor is removed pass out of a small port to the atmosphere. The amount of vented gas is estimated to be only about ten per cent of the total quantity generated by the arc, thus making possible almost complete enclosure of the interrupter. Water and steam that may be forced out around the upper contact guide is not thrown out of the breaker but only up into the mechanism chamber. Leakage from the chamber is avoided by providing a close-fitting bushing for the rotating shaft which operates the arcing and disconnect contacts.

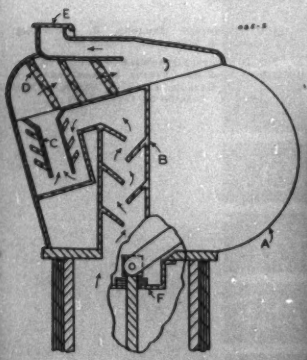

Figure 5. Steam condensing and venting channels

A—Mechanism chamber
B—Baffled passage beside mechanism chamber
C—Centrifugal separator
D—Metal screens
E—Hinged cover
F—Upper contact guide

Test Results

In table I are recorded a few of the results from the many series of interrupting tests on this water-breaker pole unit. A current range of 50 to 61,000 amperes at 13,200 volts is covered in these tests, the arcing time averaging close to $1^1/_2$ cycles for all currents. Oscillograms of representative opening and close-open interruptions are shown in figures 6, 7, 8, and 9. These show that for only the last one or two half-cycles of this time is there appreciable arc voltage, indicating effective action as soon as flow through the arcing chamber is established. The closing of high currents on the air-disconnect-switch contacts is accomplished with very little arcing due to the high-speed snap action. On the opening stroke, this switch shows a small spark when clearing the very low residual current conducted through the water in the arcing chamber immediately following the interruption of the main arc. The burning at the main contact and fingers is found to be very moderate considering the length of the current path through the arcing contact and disconnect switch to which the short-circuit current must be transferred by the opening of the main paralleling switch.

Distilled water is used in the breaker, samples from the interrupter usually measuring about 100,000 ohm-centimeters just after filling. The tests indicate that 100 or more low- and medium-current interruptions can be made before the resistivity will go to a value which indicates the need for water replacement. From four to six short circuits in the range from 40,000 to 60,000 amperes can be interrupted without changing the water in the breaker. The interrupting effectiveness of this water breaker design is clearly demonstrated by the fact that although the full operating line voltage was applied across a single-pole unit, the arc was quickly extinguished after separating the arcing contacts only a few inches in the single interrupting chamber.

Figure 7. Oscillogram of close-open test interrupting 29,000 amperes at 13,200 volts

Figure 8 (above). Oscillogram of opening test interrupting 58,000 amperes at 13,200 volts

Figure 9 (below). Oscillogram of opening test interrupting 61,000 amperes at 13,200 volts

Advantageous Design Features

Features of particular interest in the design of the water breaker just described are as follows:

(*a*). The bottom bell *D*, figure 4, is readily removable for access to the stationary contact structure without disturbing the mounting of the pole unit.

(*b*). Because of the top enclosure of the pole unit, very little water or gas can escape into the surrounding air when the breaker is opening short circuits. The outlet for gas is designed to strain moisture from it before it reaches the atmosphere.

(*c*). No porcelain is used in the construction of this breaker.

(*d*). The main current-carrying loop being at the rear of the pole unit is of minimum length, and the severe mechanical strains caused by short-circuit currents which occur in many designs are not present in this one.

Conclusions

Tests on a high-power water breaker have shown that water can be used as an arc-extinguishing medium with results comparable to an oil circuit breaker. With proper precautions in the design which take into account the relatively low dielectric strength of water and the possibilities of corrosion, the water breaker becomes very interesting. As further experience is obtained it may find a place in the field of oilless switchgear for central-station service in America as it has in Europe.

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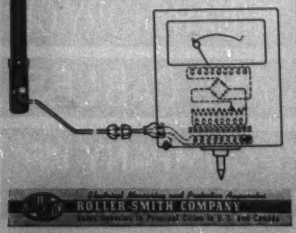

Electrical Measuring and Protective Apparatus
ROLLER SMITH COMPANY
Sales Offices in Principal Cities in U. S. and Canada

Trade Literature

[Mailed to readers free—unless otherwise noted—upon request to companies named]

Insulating Tubing.—Bulletin. Describes "Irv-O-Volt Varnished Inside-and-Out Tubing"; includes sample length of the tubing. Lists 12 outstanding advantages and includes data on ASTM tests, uses, available sizes, color and cost. Irvington Varnish & Insulator Co., Irvington, N. J.

Non-Magnetic Steel.—Bulletin, 4 pp. Describes a uniform, high quality steel, possessing low magnetic permeability, high electrical resistance and good machining qualities. Applications to electrical apparatus are listed and electrical and physical properties are given. Jessop Steel Co., Washington, Pa.

Resistance Decades.—Bulletin 825. Describes a complete line of resistance decades, including units for every purpose. Also contains information on unmounted decade resistances, wire wound resistors, rotary instrument switches, binding posts, and decade potentiometer. Shallcross Mfg. Co., Collingdale, Pa.

Oscillograph. Bulletin, 8 pp. Describes type 208 cathode-ray oscillograph, designed to operate the modern high-vacuum cathode-ray tube as an oscillograph with sufficient flexibility, associated circuits and convenience of control, to facilitate its application to the majority of all laboratory requirements. Allen B. DuMont Laboratories, Inc., Passaic, N. J.

Mica Insulation.—Bulletin (1). 4 pp. Describes composite bonded mica insulation, (Super-Nemcoite) for use in electrical equipment and machinery; available in flexible and rigid plate form, tubing and fiberglas-mica. Bulletin (2) 4 pp., describes Y-26 and Y-27 composite bonded high heat mica plates for all types of heater appliances, available in sheets of any thickness or in punchings of any shape. These "Y" built-up mica plates are said to withstand the same maximum temperatures as natural mica. New England Mica Co., Waltham, Mass.

Wire Size Calculator.—The Bull Dog "Handy Calculator" is based on the 1940 National Electrical Code and is a revision of the original calculator, first copyrighted in 1935. One side of this slide device is devoted to wire sizes, capacities, and conduit data, with respect to Code grade wire, performance grade, and heat resistant grade. The amperage correction factors for all three grades of wire are also shown. The other side of the calculator gives data for wiring motor circuits, including the wire size, conduit size for each grade of wire, and the fuse and branch circuit capacities for each different motor size. The calculator will be helpful to installers of electrical material, the nature of whose work requires frequent reference to the Code. Bull Dog Electric Products Co., 7610 Jos. Campau Ave., Detroit, Mich.

Motors.—Bulletin 119, 4 pp. Describes AA squirrel-cage induction motors for 2- and 3-phase a-c circuits, 40°C, continuous duty, open rating; capacities to 250 hp. Reliance Electric & Engineering Co., 1088 Ivanhoe Rd., Cleveland, Ohio.

Cutouts.—Bulletin 102, 16 pp. Describes open type cutouts, fuse switches and accessories. Many improvements and some additions to the line are covered; price list is included. W. N. Matthews Corp., 3722 Forest Park Blvd., St. Louis, Mo.

Pyrometers.—Catalog 1101F, 32 pp. Describes electric thermometers, pyrometers, high speed photoelectric action; indicating or recording controllers, recorders and resistance thermometers are covered. C. J. Tagliabue Mfg. Co., Park & Nostrand Aves., Brooklyn, N. Y.

CLASSIFIED ADVERTISEMENTS

RATES: Fifty cents per line; minimum charge based on use of five lines; maximum space not to exceed thirty lines. Copy is due the 15th of the month preceding publication date.

WANTED: Transformer Designing Engineer with experience in design of small distribution transformers. Location northern Ohio. State age, salary expected, and full details of experience in first letter. Position permanent. Address Box 204, ELECTRICAL ENGINEERING, 33 West 39th St., New York City.

WANTED: Recent college graduate with knowledge of electricity or metallurgy or both, to do experimental work. Write full particulars of training, age, salary expected, etc. to Box 207, ELECTRICAL ENGINEERING, 33 West 39th St., New York City.

ELECTRICAL ENGINEERS

SQUAD LEADER, CHECKER AND DESIGNER FOR STEEL PLANT DESIGN. EXPERIENCE IN POWER GENERATION AND DISTRIBUTION, CONTROL EQUIPMENT, OR MILL DRIVE AND AUXILIARY MOTORS ESSENTIAL. APPLY STEPHEN DERRY, EMP. DIRECTOR, ARTHUR G. McKEE & COMPANY, CLEVELAND, OHIO. CONSIDERATION GIVEN ONLY TO THOSE GIVING DETAILED EXPERIENCE, SALARY AND DATE AVAILABLE.

WANTED: Junior Electrical Engineering Draftsman preferably under 35, with experience in substation design. Salary in accordance with experience. Location approximately 100 miles from Philadelphia, Pennsylvania. Address Box 209, ELECTRICAL ENGINEERING, 33 West 39th St., New York City.

SEE ALSO PAGE 21

Learn a lesson from a ship story about Fiberglas* Electrical Insulation

LISTEN TO THIS: a brand-new 800 K.W. generator was recently installed in an overworked English liner. Its coils were wound with Class A insulation. The slot insulation was Class B.

And what happened?

The insulation failed on its first trip . . . leaving the ship's pumps, fans, blowers, and other electrical equipment without current.

So, the generator was rewound by Electrical Engineers, Inc. This up-to-the-minute organization uses Fiberglas insulation *exclusively* for Class B requirements. They used Fiberglas on the generator, and since then . . .

. . . the ship has been in grueling, continuous service, with *no failure* of its main power plant.

Moral: If you have a tough job for electrical insulation—use Fiberglas. Experience in scores of U. S. industries proves that proper application of Fiberglas enables *other* types of equipment to stand up where they previously failed in service with other insulations.

And, Mister, that saves money!

How About Fiberglas For Normal Service?

Suppose your generators, motors, or other electrical equipment have been working under entirely normal conditions. No overloads. No excessively high temperatures . . . no acids, oils, dusts, or dampness. Can Fiberglas help *you*?

You bet it can! Take motors—

Chances are . . . your motors will be working more and *more* hours now that all industry is moving ahead on faster schedules. Therefore, downtime on your equipment due to motor failure is an increasing danger.

You can obtain the maximum safety factor, as other companies have, by insulating your standard-size motors with Fiberglas!

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Wouldn't it be wise, then, for you to protect yourself against downtime losses, by protecting your equipment with Fiberglas? Do that. Specify Fiberglas Electrical Insulation. *Owens-Corning Fiberglas Corporation, Toledo, O. In Canada: Fiberglas Canada, Ltd., Oshawa, Ont.*

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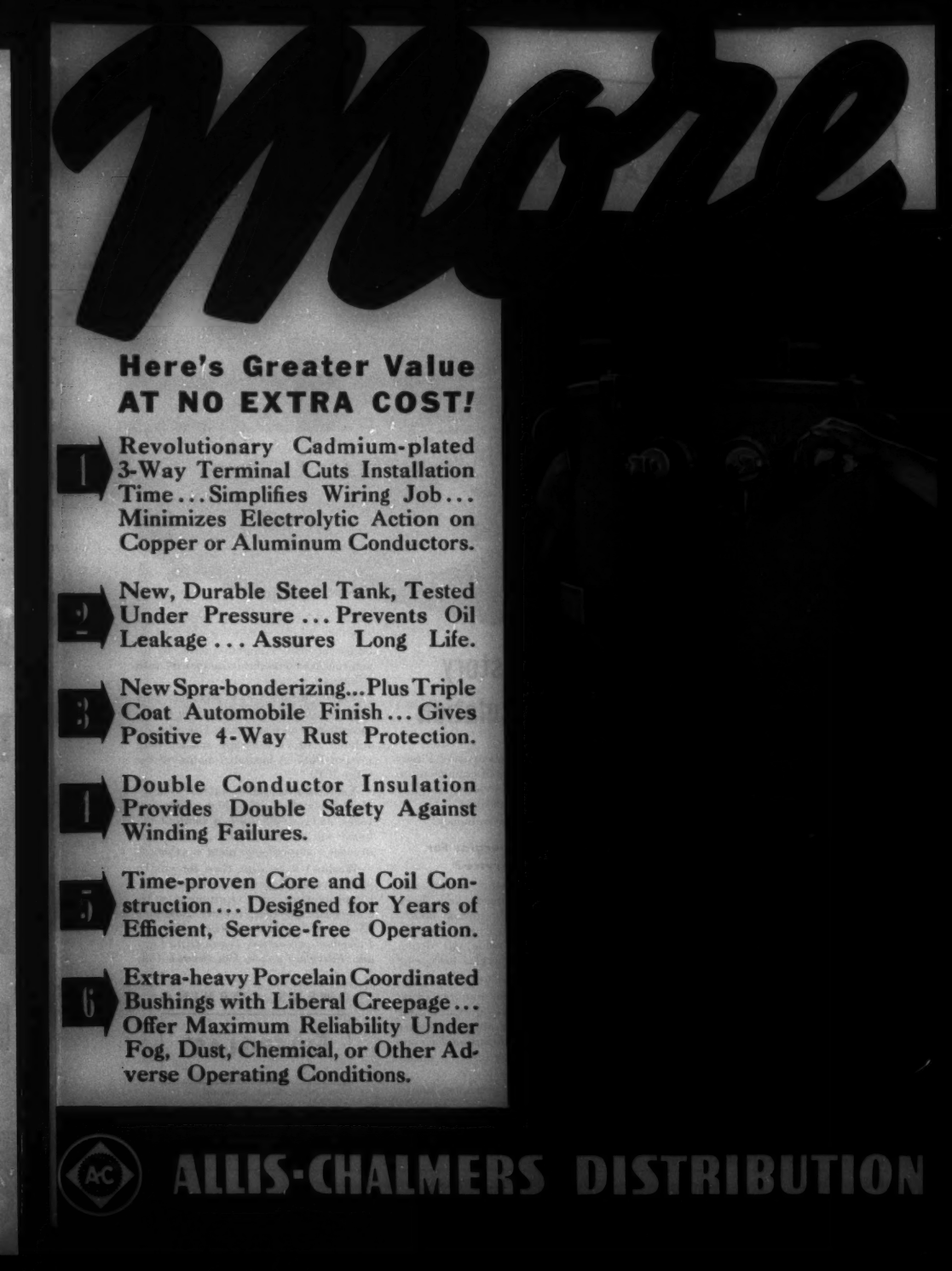
TO ELECTRICAL ENGINEERS: Not only for motors and generators, as described above, but for all types of electrical equipment—Engineers have found *and used* the superior qualities of Fiberglas for electrical insulation. Why not you? You can get Fiberglas in all standard forms. Write to us today.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New Allis-Chalmers Distribution Transformer First With Cost Cutting Improvements!

Added quality in every detail . . . added design features that point the way to greater all-around dependability at lower costs — that's the new Allis-Chalmers Distribution Transformer . . . on the market today!

With the big cadmium-plated 3-way terminals you save man hours . . . eliminate complicated wiring jobs.

Equally important . . . you don't have to buy special fittings . . . for the heavy cadmium plating not only reduces corrosion . . . but at the same time actually minimizes electrolytic action when used with copper or aluminum conductors.

What's more, there's new design perfection of core and coils . . . dictated by over 40 years of Allis-Chalmers experience in building distribution and power transformers for utilities all over the world. All windings are double insulated for added safety — double protection against winding failure.

But that's only part of the story! This new Allis-Chalmers Distribution Transformer . . . with all its money saving features costs no more than ordinary distribution transformers.

For complete information . . . call the nearest Allis-Chalmers District Office . . . or write Allis-Chalmers, Pittsburgh Works, Pittsburgh, Penn.

SEE HOW THE NEW 3-WAY TERMINAL WORKS! Perfected 3-Way Terminal is standard equipment on all new Allis-Chalmers Distribution Transformers. First and second pictures show how simply and easily leads are brought to the transformer from both top and bottom. But you don't stop there! For in the third picture is illustrated an extra advantage you get with no extra cost at all. If necessary . . . leads can be brought straight out from the transformer . . . without making an extra bend in the conductors or complicating the wiring job. Notice how the tightening tool travels in an up and down direction, eliminating the chance for accidental short circuits across the secondary terminals. Notice, too, that a standard line-man's wrench is used. No special tools are needed. You don't have to buy extra fittings. Heavy cadmium plating of the 3-Way Terminal makes it possible to be used with both copper and aluminum conductors with a minimum of electrolytic action.

TRANSFORMERS *Cut Operating Costs*

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Whether you're concerned with switches, bushings, transformers, cables, potheads, or circuit-breakers, our belief is that it will pay you to investigate Armstrong's Corprene. "Corprene" is the trade name for a group of more than two dozen cork-and-synthetic-rubber compositions—made in sheets, cut pieces, and molded forms. These materials are impervious to liquids and gases and highly resistant to their destructive effects; also to those of sunlight and corona. Corprene seals can be depended upon to keep oil in and moisture out—*for the life of your equipment.* Furthermore, their physical characteristics (such as compressibility and lateral flow) are readily "tailor-made" to individual requirements.

That's why Westinghouse, for instance, uses Corprene gaskets in its transformers; and why Line Material Company protects the isolators in its lightning arresters with Corprene gaskets. And why *millions* of Corprene gaskets, packings, washers, and other sealing units are serving industry today—efficiently.

How to Quell a Sealing Quandary

If you are up in the air over any kind of problem related to electrical equipment seals—*tell us.* We're looking for that kind of trouble. Write us today!

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INDUSTRIAL DIVISION

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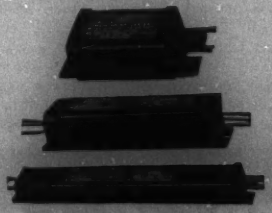
New Products

Ground Resistance Tester.—The "Direct-R" ground tester introduced by the Copperweld Steel Co., Glassport, Pa., is an inexpensive, self-contained test set for measuring the resistance to ground of a ground electrode. While its average accuracy, within its range (1–1000 ohms) is comparable with

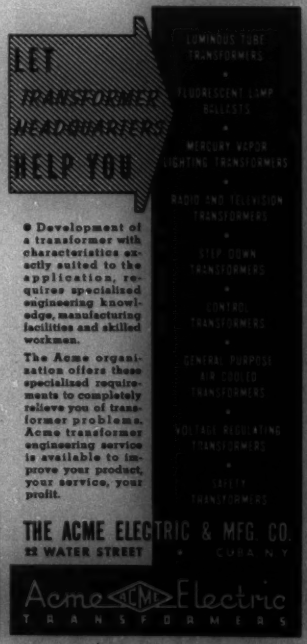
all other accepted ground testing instruments, it cannot be used for fractional ohm readings. It is intended to provide a simple instrument which will accurately indicate whether the resistance of a ground, to use one example, is ten, fifteen, or fifty ohms. The new tester is inexpensive, easy to operate and weighs only 9½ pounds. Among other advantages, it allows wide variation in resistance of auxiliary ground rods; provides for direct reading in ohms on a linear scale; utilizes one meter instead of two. Also, it provides compensation for change in battery voltage due to aging and use; provides a method for reducing to a minimum the effects of polarization, stray currents, and galvanic action; provides for multiple resistance range. Its accuracy is comparable with all accepted methods of measuring resistance to ground of electrode; it can be used for a general purpose resistance meter, or a continuity meter. Two auxiliary ground electrodes, two 40-foot test leads and one 10-foot test lead are carried in separate compartment in the instrument case.

Fluorescent Lamp Ballasts. A new line of fluorescent lamp ballasts introduced by the Acme Electric & Mfg. Co., Cuba, N. Y., is said to provide performance characteristics which coincide exactly with the requirements of the fluorescent type lamps they are designed to power. Unlike incandescent lamps which will operate to a degree of satisfaction over a considerable voltage range, the fluorescent type lamp requires exact voltage matching to perform satisfactorily. According to the manufacturer, the new ballasts achieve this important requirement, providing the secondary results of quick starting, humless operation. The units are available in designs for single lamp applications of 15, 20, 30, 40, 65, and 100 watts, and are also made in double lamp applications of same lamp sizes. Testing samples are offered to fluorescent fixture builders and descriptive bulletin is available.



Air-Cooled Regulator.—A new, dry-type, air-cooled regulator for feeder voltage regulation, available in ratings of 36 kva to 96 kva, 2,400 volts, single phase, has been introduced by the Allis-Chalmers Mfg. Co., Milwaukee, Wis. The regulator is of the step type, having thirty-two ⅝ per cent steps to provide ±10 per cent regulation. The transformer is completely air-cooled, without blowers or forced ventilation of any kind, and the tap changer operates in air without lubrication. The unit has a wide application in indoor substations where reduction of fire hazard is of vital importance and where it is generally undesirable to have special non-inflammable insulating liquids.

(Continued on page 14)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- **HIGH EFFICIENCY**—Exceptionally low losses at both no load and at full power.
- **SMALL SIZE**—VARIACS are much smaller than any other voltage control of equal power rating.
- **LINEAR OUTPUT VOLTAGE**—Output voltages are continuously adjustable from *zero* by means of a 320 degree rotation of the control knob.
- **CALIBRATED DIALS**—VARIACS are supplied with reversible dials which read directly in output voltage from zero to line voltage or from zero to 15% above line.
- **SMALL TEMPERATURE RISE**—Less than 50 degrees C. for *continuous duty*.
- **ADVANCED MECHANICAL DESIGN**—Rugged construction—no delicate parts or wires, two or more units may be ganged on the same shaft to control several circuits simultaneously or to increase the total power rating.

VARIACS are stocked in fifteen models with power ratings from 170 watts to 7 kw; prices on the stock models range between $10.00 and $100.00.

**Trade name VARIAC is registered at U. S. Patent Office. VARIACS are patented under U. S. Patent 2,009,013 issued to General Radio Company.*

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3. Only one set of connections.
4. No adjustments or "balancing".
5. Covers a wide range of resistance.
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FOR MEASURING RESISTANCE TO EARTH OF ALL TYPES OF ELECTRICAL GROUND CONNECTIONS.

Write for illustrated Catalog 1645-EE describing the "Megger" Ground Testing Instruments.

James G. Biddle Co.

1211-13 ARCH STREET *Electrical and Scientific Instruments* PHILADELPHIA, PA.

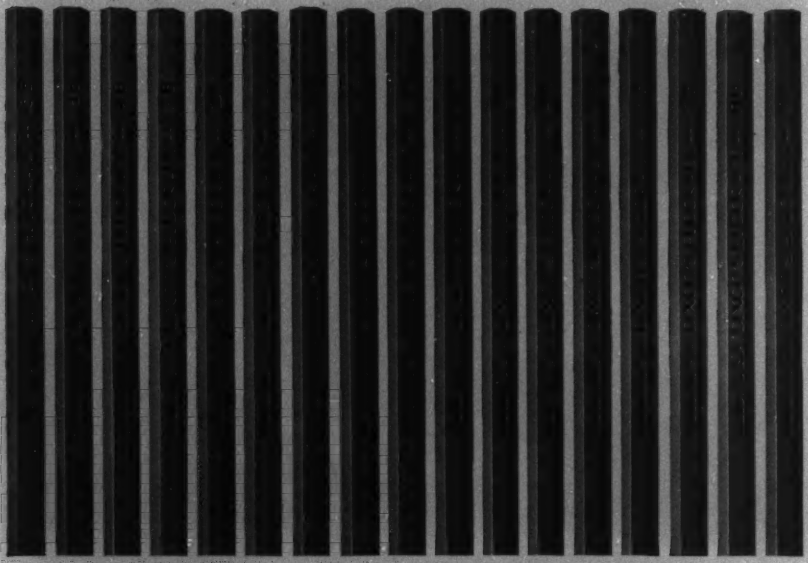
New Products

(Continued from page 12)

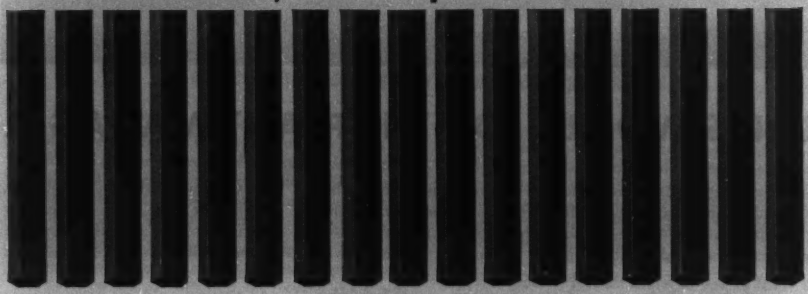
Synchronous Program Clocks.—Two new program clocks for operating time signals, manufactured by the Zenith Electric Co., 845 S. Wabash Ave., Chicago, Ill., will operate a signal at any 5-minute or 1-minute periods, respectively. These clocks have a large, legible 24-hour dial and a 1-hour dial cam. Pointers, connected to a contact arm, ride the dials and permit the contact arm to fall only when preset time is reached. They are operated by heavy duty, synchronous motors and contacts can be so arranged as to operate a signal either in one ring or a coded ring, or for a definite duration of time, from 2 to 6 seconds. Units are compact and enclosed in dust-proof case. These clocks can be built to operate for many different purposes such as daily siren testing, timing industrial processes, and signaling the start and end of operating periods.

Temperature Indicator.—With this portable instrument, in thermocouple temperature measurements, checking thermocouples or measuring small emf's, additional precision can be obtained without increase in instrument cost, by sacrificing the convenience of a reference-junction compensator, according to the manufacturer, Leeds & Northrup Co., 4932 Stenton Ave., Philadelphia, Pa. Increased accuracy has been provided in this No. 8067 indicator by calibrating only a small portion of the range on a continuously adjustable slidewire. The remainder, adjustable in fixed steps, is on a dial switch of ten highly accurate resistors. Range is from 0 to 111 millivolts with a limit of error of ±0.1 millivolt. Completely self-contained, the new potentiometer is light and compact.

TYPHONITE ELDORADO PENCILS



17 DEGREES, *like 17 parallel lines . . .*



. . . THEY NEVER MEET!

Never will you pick up a Dixon's *Typhonite* Eldorado stamped "2H" and find that it is a "3H" or an "H" in performance. Like parallel lines, the 17 degrees of *Typhonite* Eldorado never meet. Such uniformity is possible only because Eldorado leads are made from *Typhonite* particles that are minute twins. Each particle is minute in size, and each is the same size.

To achieve this perfection Dixon creates a new form of graphite in a typhoon of superheated steam. This new form is called *Typhonite* and the *Typhonite* process is exclusive with Dixon.

But uniformity is not all you should ask of a drawing pencil. Its lead must be strong and dense and smooth. Test *Typhonite* Eldorado for these qualities. And make the tests tough.

To test for strength, sharpen a *Typhonite* Eldorado to the finest point. To convince yourself that Dixon's *Typhonite* Eldorado pencils are smooth and opaque even in the hardest degrees, test the H degrees. Make these tests and know that there is no other pencil like Dixon's *Typhonite* Eldorado.

Your dealer carries Dixon's *Typhonite* Eldorado.

Pencil Sales Department 42-J2

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for motors, generators and transformers

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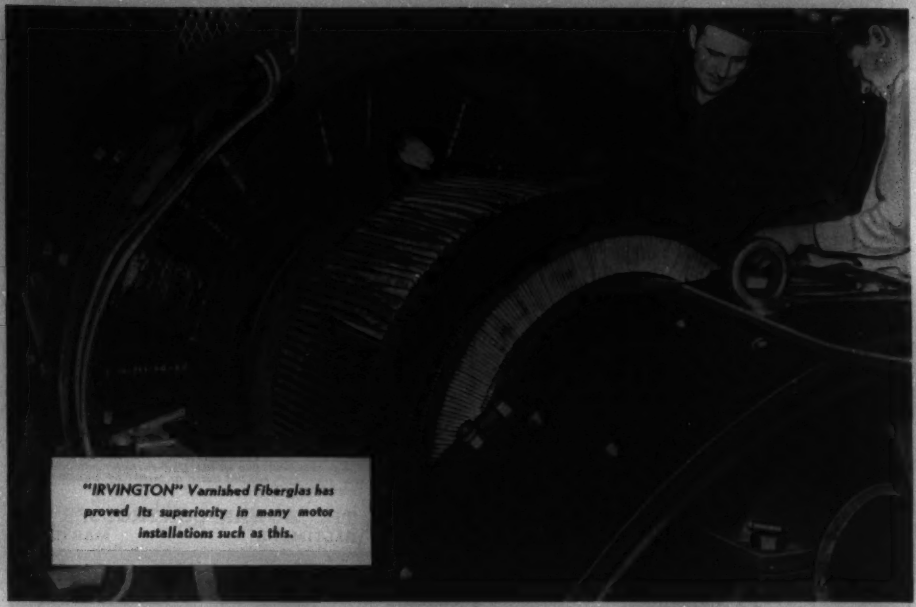
Scully Steel Products Company, Chicago, *Warehouse Distributors*
United States Steel Export Company, New York

UNITED STATES STEEL



"IRVINGTON" Varnished Fiberglas has proved its superiority in many motor installations such as this.

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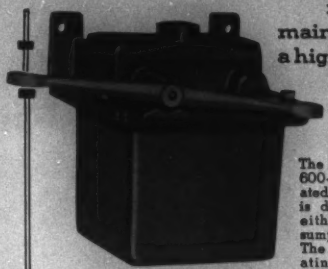

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The Type 600-1 switch has a liberal rating and can be used either as a pilot switch or for direct operation of fractional horsepower motors.

Bulletin 3911 on request.

Type 600-1 switch designed to conform with the manufacturer's interpretation of the Underwriters' Laboratories, Inc. standards but not listed or tested by Underwriters Laboratories, Inc.

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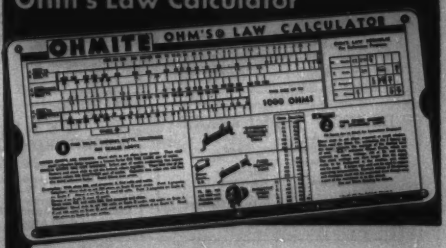

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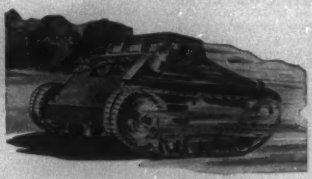

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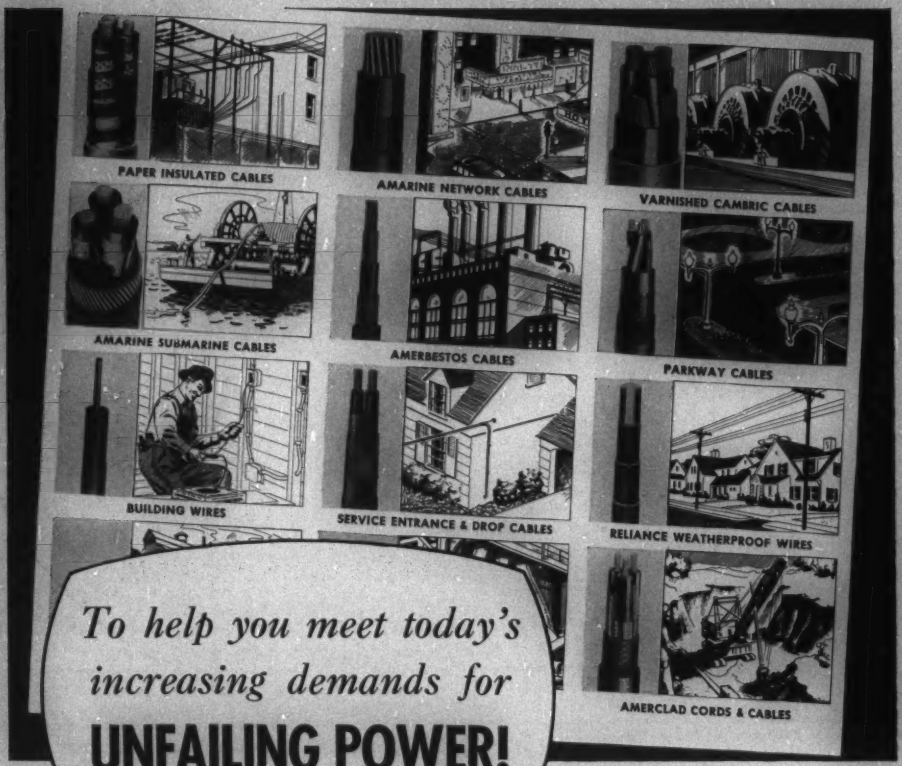
Right: Knob has been turned to left opening jaws of mechanism. Bare section of line lead is ready to be inserted. All metal parts of the mechanism are entirely surrounded by porcelain.

Below: Knob has been turned to the right; clamping mechanism has been closed, securely gripping the lead wire.



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